Culminating Report

Laboratory Building

Sandia National Laboratories, Albuquerque, NM

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ACRONYMS AND ABBERVIATIONS

The following are acronyms and abbreviations utilized in this Life Safety Analysis

ABA	Architectural Barriers Act
ADA	American with Disabilities Act
ASET	Available Safe Egress Time
ASTM	American Society for Testing and Materials
cd	Candela
CO	Carbon Monoxide
DACR	Digital Alarm Communicator Receiver
DACT	Digital Alarm Communicator Transmitters
dBA	Decibel (A-Weighted)
DETACT	Detector Actuation
DOE	Department of Energy
EST	Edwards Signaling Technology
FACP	Fire Alarm Control Panel
FATC	Fire Alarm Terminal Cabinet
FDC	Fire Department Connection
FDS	Fire Dynamics Simulator
FED	Fractional Effective Dose
HRR	Heat Release Rate
HRRPUA	Heat Release Rate per Unit Area
HSSD	High Sensitivity Smoke Detection
IBC	International Building Code
IDC	Initiating Device Circuit
IFC	International Fire Code
ITM	Inspection Testing and Maintenance
KAFB	Kirtland Air Force Base
LSC	Life Safety Code (NFPA 101)
NA	Notification Appliance
NFPA	National Fire Protection Association
OL	Occupant Load
OS&Y	Outside Screw and Yoke
QS4	QuickStart 4
RMV	Respiratory Minute Volume
RSET	Required Safe Egress Time
SDC	Signaling Device Circuit
SFPE	Society of Fire Protection Engineers
SNL	Sandia National Laboratories
SPL	Sound Pressure Level

1.0 EXECUTIVE SUMMARY

The purpose of the culminating report was to perform a prescriptive-based and performance-based analysis on the fire and life safety systems in the laboratory building at Sandia National Laboratories (SNL). The prescriptive-based analysis determined if the laboratory building met applicable code requirements for life safety systems. The performance-based analysis conducted a series of fire scenarios to ensure the fire and life safety systems provided adequate egress time for occupants in the event of a fire.

The prescriptive-based analysis was based on the Life Safety Code (LSC) and International Building Code (IBC). The laboratory building is a mixed occupancy building. The occupancy of each area was classified according to the use of the area and the hazards that exist. The code was used to determine if the life safety systems were appropriate for each occupancy classification. Life safety systems include: egress, fire suppression, fire alarm, and structural fire protection. The capacity of the egress system was calculated and compared to the occupant load. Analysis of the fire suppression system determined if the automatic sprinkler system was built to National Fire Protection Associate (NFPA) standards. The sprinkler water demand was calculated to ensure the water supply to the building was adequate. The fire alarm system was analyzed for proper spacing of detection and notification appliances. The electrical demand of the alarm system was calculated to ensure the battery backup supply was sufficient. The structural fire protection analysis confirmed proper materials and separation requirements existed in the building.

The performance-based analysis used stakeholders' goals and objectives to select appropriate fire scenarios to test the ability of the fire protection systems. The first fire scenario was a lobby fire open to the main corridor with ineffective sprinklers. The second scenario was a portable heater fire that ignited an office workstation. The third scenario was a flammable liquid spill fire located in a high hazard area. The Society of Fire Protection Engineers (SFPE) hydraulic model, DETACT, and Pathfinder were used to calculate the required safe egress time (RSET). Fire Dynamics Simulator (FDS) was used to calculate the available safe egress time (ASET). A fire scenario was considered successful if the ASET was greater than the RSET. A qualitative risk analysis was performed in order to provide a list of prioritized recommendations to achieve a successful fire scenario.

The laboratory building complied with all aspects of the prescriptive-based analysis except for having an adequate water supply. Both the hand calculations and the designer's calculations exceeded the water supply curve. The building did not meet the performance criteria for the performance-based analysis; however, most of the criteria can be met with a few modifications to the fire protection systems.

In conclusion, the risk analysis identified the top five risks and suggested the following corrective actions: construct a wall to separate the lobby from the main corridor; ensure proper transportation and storage of flammable liquids; install manual pull stations at the exits of offices with numerous cubicles; maintain frequent inspection, testing, and maintenance (ITM); perform a hydraulic calculation using a computer model to verify

sprinkler water demand calculations. Although the laboratory building did not pass the performance-based analysis, the building is not considered unsafe because of the low probability of a fire scenario occurring. A quantitative risk analysis is recommended if the building owner would like to determine the probability of a fire scenario actually occurring.

2.0 APPLICABLE CODE

2013 NFPA 13 Automatic Sprinkler Systems Handbook
2013 NFPA 72 National Fire Alarm and Signaling Code
2012 Edition, NFPA 101 Life Safety Code (LSC)
2012 International Building Code (IBC)
2012 International Fire Code (IFC)
20th Edition, NFPA Fire Protection Handbook (NFPA HB)
SFPE Handbook of Fire Protection Engineering, 4th Edition (SFPE HB)
DOE Standard DOE-STD-1066-99 Fire Protection Design Criteria
Sandia Specification Section 15310 Automatic Sprinklers and Water-Based Fire Protection Systems, 2012 Edition
Sandia Specification 13852 Fire Alarm Systems, 2014 Edition
American with Disabilities Act and Architectural Barriers Act 2004 (ADA-ABA)

3.0 BUILDING INTRODUCTION

The laboratory building is located at Sandia National Laboratories (SNL) in Albuquerque, New Mexico. Sandia it a multi-program laboratory operated by Lockheed Martin Co. for the United States Department of Energy (DOE). The laboratory building is located just outside of Kirtland Air Force Base (KAFB) in 20 acres of open land. The building is located off the base in order to provide barrier free access to visiting collaborators.

The laboratory building is a one-story building with mechanical penthouses consisting of 97,000 square feet of offices, conference rooms, laboratories, and building services. The building houses numerous research efforts pertaining to nanoscale science research. In order to support these research efforts, the building also contains a cleanroom and a chemical stockroom. The facility is fully sprinklered per the IBC and NFPA 13 Standard for the Installation of Sprinkler Systems, 2002 Ed.

The building's construction type is classified as a Type II-B per the IBC Table 601. IBC Type II-B is equivalent to NFPA Type II(000) per LSC Commentary Table 8.1 and the provision for equivalency in LSC Section 1.4. This construction type is considered "noncombustible, unprotected", therefore noncombustible materials are used and no building elements require a fire resistance rating.

Figure 1 gives a basic floor plan of the laboratory building which will be used throughout the report.

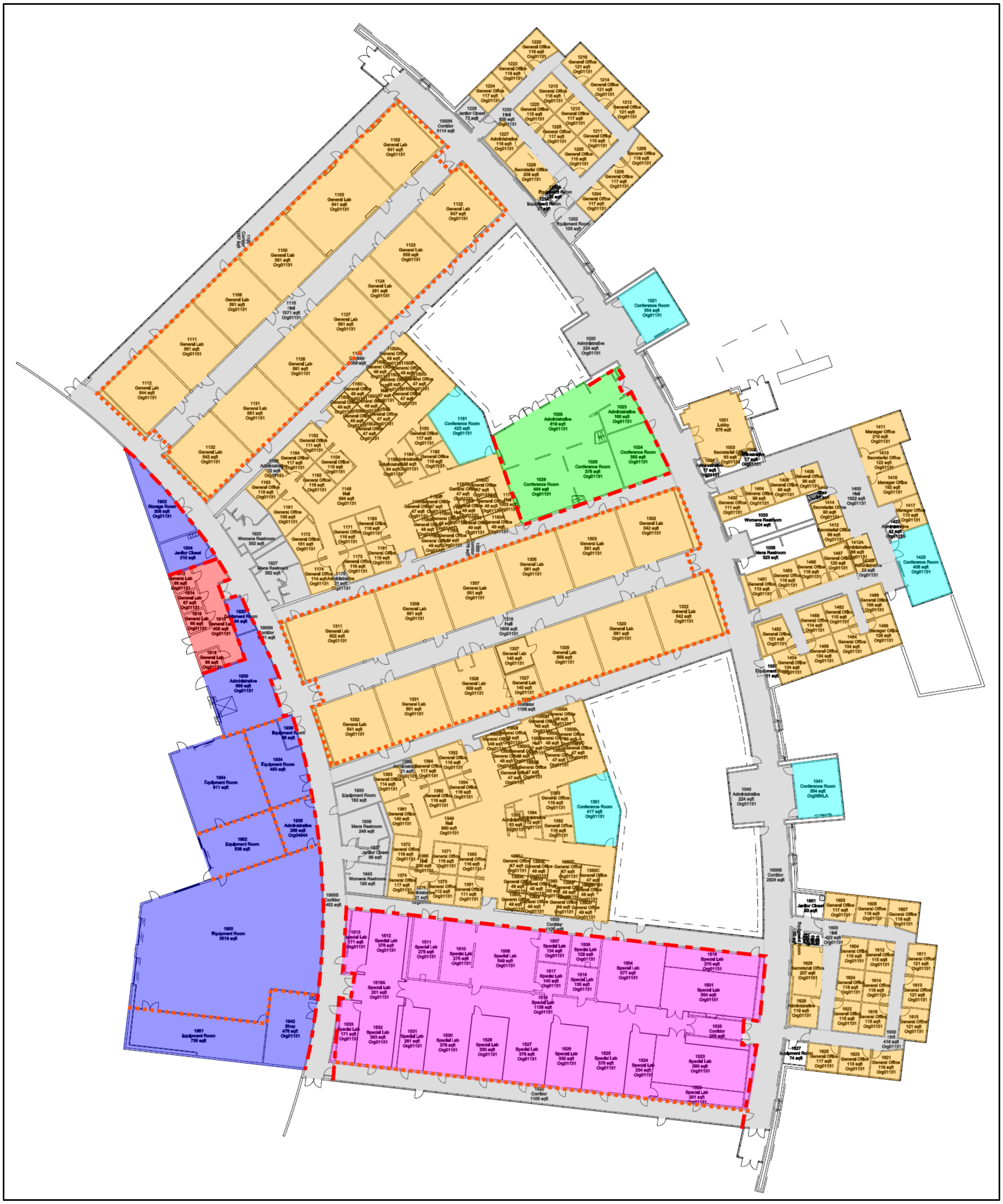

Figure 1 - Floor Plan

4.0 LIFE SAFETY ANALYSIS

4.1 Introduction to Prescriptive-Based Analysis

The following analysis is performed using the LSC and the IBC. A prescriptive-based analysis compares the building to the applicable codes and standards and provides a better understanding of where codes are met and not met within the building. The prescriptive-based analysis does not account for occupant characteristics as well as proposed uses for specific rooms. This analysis typically considers the worst case scenarios in order to ensure all future uses of the building will meet the code. Sandia uses both the IBC and the LSC. Both codes will be compared to the building, and the more stringent code will be applied to the building.

4.2 Occupancy Classifications

The laboratory building is a multiple occupancy building which meets the provisions of a separated occupancy per LSC 6.1.14.4 and IBC 508.4. *Table 1* compares the occupancy classification for the laboratory building per the IBC to the occupancy classification per the LSC:

Table 1 - Occupancy Classifications

Types of Rooms	LSC Classifications (Chapter 6.1)	IBC Classifications (Chapter 3)
Office Spaces	Business	B
Meeting Spaces (< 50)	Business	B
Laboratory Spaces	Industrial – General	B
Service Spaces	Business	B
Mechanical Rooms (Penthouse)	Industrial – General	B
Assembly Space	Assembly	A-3
Main Mechanical Room	Industrial – General	F-1
Main Electrical Room	Industrial – General	F-1
Boiler Room	Industrial – General	F-1
DI water equipment room	Industrial – General	F-1
Loading Dock Area	Industrial – General	F-1
Janitors Office Area	Industrial – General	F-1
Chemical Stockroom	Industrial – High Hazard	H-3
Cleanroom Spaces	Industrial – High Hazard	H-5
Mechanical Room (directly above cleanroom)	Industrial – High Hazard	H-5

4.3 Occupant Loads

A comparison of occupant load factors from the IBC and the LSC can be found in *Table 2* below. The occupant load factors are in terms of floor area in square feet per occupant (ft^2/person). Their values are taken from IBC Table 1004.1.2 and LSC Table 7.3.1.2.

Table 2 - Occupant Load Factor

Use	LSC Load Factor (ft^2/person)	IBC Load Factor (ft^2/person)
Assembly	15 net	15 net
Business	100	100
General and High Hazard Industrial	100	-
Group H-5	-	200
Storage	500	300
Mechanical Rooms*		300

**The mechanical rooms will be "General and High Hazard Use" for the LSC Load Factor*

An occupant load was not calculated for the penthouses on the roof because they are not occupiable spaces per LSC 3.3.268.1.

Based on *Table 1* and *Table 2*, it is clear that the IBC offers more specific occupancy classification for the laboratory building while keeping similar load factor requirements as the LSC. Storage use is the only major difference between the two load factors. LSC sets its storage load factor at $500\ ft^2/person$ while IBC's is at 300. This is not a major concern because the largest storage room in the laboratory building is less than 500. Given the appropriateness of the IBC, the occupant loads will be conducted per the IBC.

The room-by-room occupant load calculation can be found in *Appendix B: Occupant Loads*. In this appendix, the building was divided into 13 sections for ease of calculating occupant load and egress capacity. Sections 11 and 12 are the north and south courtyards respectively. The occupant load for each section of the building is shown in the following table.

Table 3 - Occupant Load by Building Section

Section	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**TOTAL**
Occupant Load	18	45	18	27	32	65	76	65	75	134	124	213	80	**972**

The following table offers a breakdown of occupant loads by use:

Table 4 - Occupant Load by Use

Use	Factor (ft^2/person)	Load
Assembly	15 net	627
Business	100	298
Group H-5	200	27
Storage	300	2
Mechanical	300	18
TOTAL		**972**

4.4 Building Exits

The following section examines the number of exits required by code, the location of the exits, and the location of the exit signs.

4.4.1 Number of Exits

The IBC 1021.2.1 and LSC 7.4.1.2(1) require 3 exits for a floor with an occupant load between 501 and 1000 occupants. The laboratory building has 5 main exits and complies with the code. IBC 1021.2.1 requires mixed occupancies to have separate exits or access to exits for each occupancy classification according to IBC Table 1021.2(2). All occupancies have their own separate exits to the outside except for the A-3 occupancy; however, the A-3 occupancy has access to two or more exits on the same floor without having to cross through intervening spaces. The F-1 occupancy has numerous rooms with 1 exit; however, these rooms are separated and meet the maximum required occupants for one exit per IBC Table 1021.2(2). The LSC 40.2.4.1.2 permits Industrial – General occupancies to have a single means of egress. The laboratory building meets the number of exit requirements provided by the LSC and IBC. There are 3 stairways within the building which are used for roof access only and will be ignored for this report since they do not play a role in the means of egress a one story building. The following table summarizes the number of exits required by IBC 1021.

Table 5 - Required Exits (IBC 1021)

Occupant Load	Exits
IBC Table 1021.2(2)	1
1-500	2
501-1000	3

4.4.2 Arrangement of Exits

The laboratory building is a sprinklered building, therefore, LSC 7.5.1.3.3 requires the separation distance between 2 remote exits to be 1/3 the diagonal of the building. The diagonal of the building is approximately 430 feet. The minimum separation distance for exits is 144 ft. The closest exits are located 167 feet from each other. IBC 1015.2.1 has the same requirements as LSC 7.5.1.3.3. The location of the exits is shown on the figure in *Appendix A: Exits and Exit Signs*. The laboratory building contains equipment room door open which open from one side of a fire rated wall into a main corridor. LSC A.7.1.3.2(9)(c) permits the opening of equipment rooms into corridors provided that: 1) the space is used solely for non-fuel-fired mechanical equipment; 2) the space contains no storage of combustible materials; 3) the building protected with an automatic sprinkler system. When the movable partition wall are in place in the A-3 assembly occupancy, the north room will have an occupant load greater than 50 persons and would require 2 exits. The second exit from the north assembly room is into the north courtyard. “NO EXIT” signs would need to be placed on the exterior of these doors to notify occupants on the courtyard not to exit through the north assembly room. The laboratory building meets the exit arrangement requirements of the IBC and LSC.

4.4.3 Exit Sign Locations

The exit sign plan is located on the figure in *Appendix A: Exits and Exit Signs*. The location of the exit signs were chosen based on LSC 7.10.1.2.1, LSC 7.10.1.2.2, and IBC 1011.1. Exit signs are spaced no more than 100 feet apart.

4.5 Egress Capacity

All egress components in the building are doors. The following calculations compare the LSC “Egress Capacity” to the IBC “Means of Egress Sizing”. Egress capacity is calculated using the capacity factors from LSC Table 7.3.3.1. “Means of Egress Sizing” is taken from IBC 1005.3.2 and 1008.1.1. All assumed clear widths of single doors and double doors in the laboratory building are 34” and 64” respectively. The assembly occupancies in the laboratory building have doors which meet the LSC 13.2.3.6.2 requirement for assembly occupancies to have a main entrance which can accommodate one-half the total occupant load. The courtyards don’t have an obvious main entrance/exit required by LSC 13.2.3.6.1, however, LSC 13.2.3.7.4 permit the lack of a well-defined main entrance/exit as long as the other exits are evenly distributed along the perimeter.

Table 6 - LSC Egress Capacity

Section	OL	No. of Exits	Component	Clear Width (in)	Capacity Factor (in/person)	Capacity (people)	Compliant
1	**18**	2	Door	34	0.2	**340**	Y
2	**45**	2	Door	34	0.2	**340**	Y
3	**18**	2	Door	34	0.2	**340**	Y
4	**27**	2	Door	34	0.2	**340**	Y
5	**32**	1	Door	34	0.2	**170**	Y
6	**65**	2	Door	64	0.2	**640**	Y
7	**76**	4	Door	34	0.2	**680**	Y
8	**65**	2	Door	64	0.2	**640**	Y
9	**75**	4	Door	34	0.2	**680**	Y
10	**111**	3	Door	34	0.2	**510**	Y
11	**124**	2	Door	34	0.2	**340**	Y
12	**213**	3	Door	34	0.2	**510**	Y
Building	**972**	5	Door	64	0.2	**1600**	Y

Table 7 - IBC Means of Egress Sizing

Section	OL	No. of Exits	Element	Clear Width (in)	Width Factor (in/person)	Calculated Width (in)	Min. Width (in)	Most Stringent	Compliant
1	18	2	Door	**34**	0.15	1.35	32	**32**	Y
2	45	2	Door	**34**	0.15	3.375	32	**32**	Y
3	18	2	Door	**34**	0.15	1.35	32	**32**	Y
4	27	2	Door	**34**	0.2	2.7	32	**32**	Y
5	32	1	Door	**34**	0.2	6.4	32	**32**	Y
6	65	2	Door	**64**	0.15	4.875	32	**32**	Y
7	76	4	Door	**34**	0.15	2.85	32	**32**	Y
8	65	2	Door	**64**	0.15	4.875	32	**32**	Y
9	75	4	Door	**34**	0.15	2.8125	32	**32**	Y
10	111	3	Door	**34**	0.15	5.55	32	**32**	Y
11	124	2	Door	**34**	0.15	9.3	32	**32**	Y
12	213	3	Door	**34**	0.15	10.65	32	**32**	Y
Building	972	5	Door	**64**	0.15	29.16	32	**32**	Y

In the tables above, the occupant load of section 11 has been reduced to only account for the rooms which have partition walls which can be combined into one large assembly room. The occupant load of the entire building is a conservative estimate. In reality, the entire populations would not use 1 of the 5 major exits since many sections have their own exits to the exterior. Section 13 was not included in this calculation since it is composed of individual rooms which all have relatively small occupant loads and meet egress capacity requirements. All exits are evenly balanced within each section and the building as a whole in order to meet IBC 1005.5 and LSC 7.3.1.1.2 which requires the loss of one exit to not consume more than 50 percent of the egress capacity. Section 5 is broken up into many smaller sections by 1 and 2 hour fire barriers. In order to make a conservative calculation, the cumulative occupant load of section 5 was assumed to exit out of 1 door. Section 5 was compliant with the assumption; therefore, compliance will be maintained with the addition of more exit doors.

4.6 Travel Distance

The following table for travel distance requirements is taken from IBC Table 1016.2 and LSC Table A.7.6. All distance values are for an existing, sprinklered building.

Table 8 - Travel Distance (feet)

Occupancy	LSC	IBC	Actual
Business/B	300	300	192
Assembly/A-3	250	250	142
Industrial (General)/F-1	250	250	103
Industrial (High)/H-3	75	150	47
Industrial (High)/H-5	75	200	70

The 2 codes are almost identical except when we get into the high hazard occupancies. The LSC Industrial – High Hazard occupancy has a more stringent travel distance. The drawing in *Appendix C: Travel Distance* depicts some “worst case scenario” travel distances for each of the occupancies. Travel distances were calculated from the furthest point within an occupancy to the nearest exit. All travel distances in the laboratory building comply with both the IBC and the LSC. The H-5 occupancy is able to meet the travel distance due to the horizontal exit which encompasses the area.

4.7 Horizontal Exits

The laboratory building is separated into numerous control areas by fire barriers. Building elements such as wall and doors are assigned a fire resistance rating in accordance with American Society for Testing and Materials (ASTM) E 119. For a wall, the transmission of heat shall not raise the temperature on the unexposed surface more than 250^{o}F (139^{o}C) above its initial temperature. The passage of flame or gases shall

not be hot enough to ignite cotton waste on the unexposed side. The wall shall also be able to withstand the hose stream test without the passage of water. Fire barriers are permitted to separate the building into control areas to meet the maximum allowable quantities for hazardous material specified in IBC 414.2.1. Fire barriers separating occupancies within a building, with a 2-hour rating, can serve as a horizontal exit per IBC 707.3.10; 1025.2; therefore, occupants in the H-5 occupants meet the required travel distance once they cross the 2-hour fire barrier shown in *Appendix D: Fire Resistance Ratings*.

4.8 Fire Resistance Ratings

See Appendix D for a floor plan of the fire rated walls. The laboratory building met older editions of the IBC which required a 4 hour separation between an H-5 occupancy and an Assembly occupancy. The H-5 already had a 2 hour separations around it, so a 2 hour wall was built around the assembly occupancy in order to meet the 4 hour requirement. *Table 9* pulls required separation values from the IBC 508.4 for a sprinklered building.

Table 9 – Required Separation (IBC 508.4)

Use	A-3	B	F-1	H-3	H-5
A-3		1	2	3	4
B			2	1	1
F-1				1	1
H-3					1

The LSC has a similar table found in LSC Table 6.1.14.4.1:

Table 10 - LSC Occupancy Sepatation

Occupancy	Occupancy	Separation (hours)
Industrial – High Hazard	Assembly < 300	3
Industrial – High Hazard	Business	2
Industrial – High Hazard	Industrial – General	1
Business	Assembly < 300	1
Industrial – General	Assembly < 300	2

IBC 1018.1 requires the corridors to be shielded from H-3 and H-5 occupancies by a 1 hour fire rated wall. LSC 7.1.3.1 requires a corridor serving an occupant load greater than 30 to be 1-hour rated, however, this doesn't apply to an existing building provided that the occupancy classification doesn't change. . The corridors are shielded from the

H-3 and H-5 occupancy by a 2 hour fire rated wall. The laboratory building surpasses the IBC and LSC requirements for fire resistance ratings.

4.9 Interior Finish Requirements

The following table from the IBC is used to determine allowable finished for walls, ceiling, and floors based on the occupancy classification:

Table 11 - Interior Finish Classes (IBC 803.1.1; 804.2)

Group	Wall and Ceiling Class		Floor Class
	Corridor	Room	
B	C	C	II
A-3	B	C	II
F-1	C	C	II
H-3	B	C	II
H-5	B	C	II

The wall and ceiling classes are tested under ASTM E 84 "Standard Test Method for Surface Burning Characteristics of Building Materials" and given a flame spread index and a smoke developed index. The following table identifies the three classes per ASTM E 84:

Table 12 - Wall/Ceiling Finish Index (IBC 803.1.1; ASTM E 84)

Class	Flame Spread	Smoke Developed
A	0-25	0-450
B	26-75	0-450
C	76-200	0-450

The floor classes are determined in tested under NFPA 253 to determine the minimum critical radiant flux to prevent flame spread along the floor:

Table 13 - Floor Finish (IBC 804.2; NFPA 253)

Class	Minimum Critical Radiant Flux
I	0.45 W/cm^2
II	0.22 W/cm^2

All materials in the laboratory building are required to meet the Department of Energy (DOE) Standard, DOE Std 1066-99, which limits the flame spread to less than 25 and the smoke developed index to less than 50. These requirements are more stringent than those required by IBC Table 803.9 and LSC Table A.10.2.2; therefore, the laboratory building meets the code based on its need to follow a more stringent DOE standard. Lastly, IBC 806.1.2 limits the amount of combustible decorative material to 10 percent of the wall area.

5.0 WATER-BASED FIRE SUPPRESSION

5.1 Automatic Sprinkler System Introduction

The laboratory building is protected throughout by two electrically supervised, fully automatic, wet-pipe, hydraulically calculated sprinkler systems. The laboratory is a single story building with mechanical penthouses located on top of the building. The approximate area of the first floor is 82,500 sq. ft. which requires the laboratory building to have two separate automatic sprinkler systems in order to keep the operating area of each system less than 52,000 sq. ft. required by *NFPA 13-2013 Sect. 8.2.1*. As a Department of Energy (DOE) Facility, the laboratory building is required to meet the DOE Standard *DOE-STD-1066-99 Fire Protection Design Criteria* in addition to the IBC and applicable NFPA standards. As a Sandia facility, the laboratory building is also required to follow *Sandia Specification Section 15310 Automatic Sprinklers and Water-Based Fire Protection Systems*.

5.2 Water Supply

5.2.1 Water Supply Characteristics

Sandia National Laboratories is located on Kirtland Air Force Base (KAFB) in Albuquerque, New Mexico. Sandia connects to the KAFB water main to provide required water flow and water pressure for the automatic sprinkler system and manual firefighting operations. The fire loop contains fire hydrants spaced a maximum of 300 feet apart. The hydrants are located between 40 and 100 feet from the building. At least one hydrant is located within 150 feet of the FDC

5.2.2 Water Flow Test

A water flow test was conducted on February 28, 2007 which resulted in the following data:

Table 14 - Water Flow Test

Category	Value
Static Pressure	74 psi
Residual Pressure	52 psi
Water Flow	1451 gpm

The results of the water flow test are graphed in *Appendix I: Flow Test Summary Sheet*.

5.3 Sprinkler System Design Criteria

5.3.1 Occupancy Classification

Table 15 depicts the sprinkler system occupancy classifications of the various areas of the building under NFPA 13. The Sandia construction specification for automatic sprinklers, Sandia Spec. 15310-2012, has more stringent requirements.

Table 15 - NFPA 13 Occupancy Classification

Space	Occupancy Classification	Reference
Offices	Light Hazard	NFPA 13, 5.2
Laboratories	Ordinary Hazard (Class C Laboratory)	NFPA 13, 22.8.1 (2) NFPA 45, 6.2.1.1
Cleanrooms	Special Hazard	NFPA 13, 22.23
Flammable Liquid Storage	Extra Hazard Group 2 Special Hazard Special Hazard	NFPA 13, 5.4.2 NFPA 13, 22.2 NFPA 30, 16.5.2 IFC 5704.3.6.3
Exterior Loading Dock	Special Hazard	NFPA 13, 22.8.1 (2) NFPA 45, 6.2.1.1
Shops and Equipment Rooms	Ordinary Hazard Group 2	NFPA 30, 5.3.2

All spaces are easily classifiable by NFPA 13 except for the flammable liquid storage. The first classification of flammable liquid storage comes from NFPA 13, 5.4.2 which classifies extra hazard group 2 as an occupancy containing moderate to substantial amount of flammable or combustible liquids. The second classification comes from NFPA 13, 22.2 which considers flammable liquid storages as a special hazard and redirects you to use NFPA 30. NFPA 30, 16.5.2 contains 7 different design tables depending on the quantity of liquid, size of container, type or rack, etc. Additionally, these design tables are broken down further into 3 different design schemes, which are separated even further into their own design tables. The third classification comes from the IFC 5704.3.6.3 which contains 8 sprinkler design tables depending on the storage layout. Due to a limited knowledge of the actual flammable liquid storage room layout, container types, and quantities, we use the extra hazard group 2 design criteria.

5.3.2 Sprinkler System Design Criteria

We will now compare the NFPA 13 sprinkler design criteria to the Sandia Spec. 15310-2012 criteria. The NFPA 13 criteria were taken from the Density/Area Curves found in NFPA 13 Figure 11.2.3.1.1:

Table 16 - Sprinkler Desigin Criteria (NFPA 13 vs. Sandia Spec. 15310-2012)

Space	Classification (NFPA 13)	Density (gpm/ft^2)		Area (ft^2)		Hose (gpm)		Duration (min)
		NFPA 13	Sandia 15310	NFPA 13	Sandia 15310	NFPA 13	Sandia 15310	NFPA 13
Office	LH	0.10	0.15	1500	1500	100	500	30
Lab Class C	OH1	0.15	0.17	1500	3000	250	500	60-90
Cleanroom	SH	0.20	0.20	3000	3000	-	500	-
FLS	EH2	0.40	-	2500	-	500	-	90-120

Table 17 extracts the most stringent sprinkler design criteria from *Table 16* above:

Table 17 - Sprinkler System Design Criteria (2012)

Space	Density $(\frac{gpm}{ft^2})$	Area (ft^2)	Hose Stream (gpm)	Duration (min)
Offices	0.15	1500	500	60
Laboratories	0.17	3000	500	60
Cleanrooms	0.20	3000	500	90
Flammable Liquid Storage	0.40	2500	500	90

At the time the building was constructed, the sprinkler designer used Sandia Spec. 15310-2001. The following table indicates the design criteria used by the contractor. This will be the design criteria we will use for the hydraulic calculations in order to compare our results to the contractor’s results:

Table 18 - Sprinkler System Design Criteria (Contractor's Values - 2001)

Space	Density $(\frac{gpm}{ft^2})$	Area (ft^2)	Hose Stream (gpm)	Duration (min)
Offices	0.17	3000	500	60
Laboratories	0.20	3000	500	60
Cleanrooms	0.20	3000	500	90
Flammable Liquid Storage	0.60	Entire Storage	500	120
Other areas	0.17	3000	500	60

A map portraying the most remote areas based on the design criteria above can be found in *Appendix H: Hydraulic Calculations, Figure 53*.

5.4 Sprinkler System Location and Size

5.4.1 Location and Size of Piping

A 10-inch domestic water line connects the KAFB system to the 8-inch looped main which encompasses the laboratory building. A diagram of the 8-inch looped main is located in *Appendix F: Automatic Sprinkler System*. The 8-inch looped main contains sectional valves. The main enters the building at the west end where the line splits into two sprinkler risers. *Sandia Spec 15310 Sect. 2.06 (A)(1)* requires Schedule 10 pipe to be used for all diameters greater than or equal to 2-1/2 inches and schedule 40 to be used for diameters less than 2-1/2 inches.

The two risers divide the building in a northern and southern sprinkler coverage zone. The risers are cross connected by a normally closed valve. Each riser has its own fire department connection (FDC) at the lead-in on the west end of the building. Due to fire department response approaching from the east side of the building, an additional FDC is located near the main entrance on the east side of the building and ties into a bulk main near the entrance of the building. The FDCs are installed per *NFPA 13 Section 6.8.1*. A reduced pressure backflow preventer is located in the mechanical room just before the two risers per NFPA 13, 24.1.8.

5.4.2 Standpipe

Two standpipes run along the east corridor and two run along the west corridor. *Sandia Spec. 15310, Sect. 1.04 (B)(6)I* requires Class 1 standpipes where shown on the drawings. The two standpipes in the laboratory building have a diameter of 1-1/2

inches. The standpipes are accessible from the corridors. A fire hydrant must be located within 100 feet of the standpipe FDC per IFC 2012, 507.5.1.1

5.4.3 Waterflow Alarm (NFPA 13, 6.9)

The sprinkler system is supervised by a tamper switch on all sprinkler control valves as well as a vane type water flow indicator for each riser.

5.4.4 Backflow Preventers

The *IFC 9.3.3.5* requires potable water supplies to be protected against backflow in accordance with *IFC 9.3.3.5.1* and the *International Plumbing Code*. The backflow preventer assembly consists of two 8-inch FEBCO Model 860 reduced pressure backflow preventers with an incoming and outgoing Outside Screw and Yoke (OS&Y) valve and tamper switch.

5.4.5 Inspector's Test Valve (NFPA 13, 6.7.3)

One inspector's test valve is located on the east end of the building at the main entrance. The other test valve is located at the NW exit of the building.

5.4.6 Fire Department Connection

The two FDCs located on the west end of the building are located behind a security fence. *IFC 912.3* requires access to the FDC to be free of obstructions such as fences except when the fence is provided with proper signs and equipped with a means of emergency operation. The FDC located on the east end of the building is near the main entrance. The east FDC is located behind a decorative wall of the main entrance which poses a visibility issues from the street. IFC 912.2.1 requires FDC to be clearly visible from the street side of buildings and fully visible from the nearest point of fire department vehicle access.

5.4.7 Type of Sprinklers

All sprinkler heads in the laboratory building are listed according to NFPA 13, 6.1. The sprinklers will be ½ inch orifice, upright or pendant, standard response, ordinary temperature 155^{o}F, K-5.6 sprinklers per Sandia Spec. Table 1 except the cleanrooms and the chemical storage. The cleanrooms will use quick response sprinklers. The chemical storage will use K-11.2 sprinklers per NFPA 30-2012 Table 16.5.2.2. Ordinary temperature heads are installed in the chemical storage when most tables in NFPA 30-2013 16.5.2 require high temperature heads. Sandia Spec 15310 requires the use of flex sprinkler heads for use with dropped ceilings. The automatic sprinkler system in the laboratory building is equipped with schedule 10 sprinkler pipe for diameters of 2.5 inches and larger and schedule 40 for diameters less than 2.5 inches. The lab area contains sprinklers above and below the ceiling. The cleanroom area uses Flex Head sprinkler connections. See *Appendix G: Sprinkler Head Detail* for details on the sprinkler heads used in the laboratory building.

5.5 Hydraulic Calculations

NFPA 13 Chapter 23 was referenced while performing hydraulic calculations.

5.5.1 Hydraulic Hand Calculations

For this example, we will hydraulically calculate the northern most ordinary hazard area from *Appendix H: Hydraulic Calculations*, *Figure 53* with a density of 0.17 gpm/ft^2 and a design area of 3000 ft^2. A more detailed image of this area can be seen in *Figure 54*. The hydraulic calculation performed manually using Microsoft Excel and it can be found in *Table 61*. Additionally, *Table 62* to *Table 66* are pressure balances that are used are various nodes during the hydraulic calculation process. *Table 61* depicts a flow and pressure at the base of the riser (BOR) of 725 gpm and 68.1 psi respectively. These values are relatively close to the computer calculated values reported by the designer of 755.46 gpm and 59.55 psi.

Performing the hydraulic calculations proved to be a challenge because of the lack of symmetry in the sprinkler system. This lack of symmetry required a separate branch equivalent K-factor for each branch line. The irregular layout also made pressure balancing at the nodes more difficult. A major assumption made on the Excel sheet was the use of an average S and L value in order to calculate the protection coverage area per *NFPA 13-2013 Sect. 8.5.2*:

$$A_s = S \times L$$

The values of S and L were assumed to be 10 ft. and 8.5 ft. respectively by examining the drawing.

5.5.2 Water Demand

The flow test summary sheet can be found in *Appendix I: Flow Test Summary Sheet*, *Figure 55*. The sheet compares the water supply to the sprinkler and hose stream demand. Sandia Spec requires an 85 percent limit on the supply curve which is shown on the summary sheet. The manually calculated sprinkler demand from “Appendix H: Hydraulic Calculations” exceed the 85 percent supply limit; therefore, the supply is not adequate. The designer’s demand calculations meet the 85 percent supply limit, prior to adding the hose stream allowance. After the hose steam allowance is added to the sprinkler demand, the designed calculations exceed the 85 percent supply curve as well.

5.6 Inspection Testing and Maintenance (ITM)

The IFC 901.6.1 requires the Inspection, Testing, and Maintenance of a water-based fire protection system to follow NFPA 25. Below is a list compiling inspection, testing, and maintenance requirements for major sprinkler system components installed in the laboratory building. Sprinkler system requirements are taken from NFPA 25-2014 Table 5.1.1.2, standpipe requirements come from Table 6.1.2, and valve/trim requirements from Table 13.1.1.2.

Table 19 - ITM Requirements

Component	Inspect	Test	Maintenance
Waterflow alarm devices	Quarterly to verify they are free of physical damage (5.2.5)	Semiannually (5.3.3.2)	
Valve Supervisory signal devices	Quarterly to verify they are free of physical damage (5.2.5)	Quarterly to verify they are free of physical damage (13.3.2.1.2)	
Gauges	Quarterly to ensure normal water supply pressure (5.2.4.1)	5 years (5.3.2) (13.2.7.2)	
Hydraulic Nameplate	Quarterly (5.2.6)		
Hanger/seismic bracing	Annually from floor level (5.2.3)		
Pipe and fittings	Annually from floor level (5.2.2)		
Sprinklers	Annually from floor level (5.2.1) Annually inspect spares (5.2.1.4)	At 50 years and every 10 years thereafter (5.3.1.1.1) Fast-response at 20 years and every 10 years thereafter (5.3.1.1.1.3)	
Antifreeze Solution		Annually before the onset of freezing weather (5.3.4)	
Piping (Standpipe)	Visually inspected annually (6.2.1)		
Gauges (Standpipe)	Quarterly to ensure normal water supply pressure (6.2.2)		
Hydraulic Design Information (Standpipe)	Annually (6.2.3)		

Hydrostatic Test (Standpipe)		5 years (6.3.2)	
Flow Test (Standpipe)		5 years (6.3.1)	
Hose Connections (Standpipe)			Annually (Table 6.1.2)
Control Valves	Sealed weekly (13.3.2.1) Locked for electrically supervised monthly (13.3.2.1.1)	Check position and operation annually (13.3.3.1) Supervisory (13.3.3.5)	Annually (13.3.4)
Check Valves	5 years (13.4.2.1)		
Backflow preventer	Weekly/monthly (13.6.1)	Annually (13.6.2)	
Main drains		Annually for each water supply lead-in (13.2.5) (13.2.5.1) Any time the control valve is closed and reopened at system riser (13.3.3.4)	

6.0 FIRE ALARM SYSTEM

6.1 Fire Alarm Characteristics

The laboratory building is monitored by a proprietary supervising station. The station is located on KAFB and monitors all of SNL Albuquerque location. The station utilizes a Digital Alarm Communicator Receiver (DACR) to receive alarms from Digital Alarm Communicator Transmitters (DACT) located in the fire alarm control panel (FACP). The laboratory building is located just outside the gates of Kirtland AFB; therefore, a quick detection time is imperative to give the fire department enough time to respond to a fire.

The FACP is an Edwards Signaling Technology (EST) QuickStart (QS4) Intelligent Control Panel. The panel can support up to 1,000 intelligent detectors and modules along with 48 conventional class B or 40 Class A/B initiating device circuits (IDC).

One discrepancy with the fire alarm drawings furnished by the contractor is the location of the FACP. The "Fire Alarm Riser Diagram" states that the FACP is located in the lobby; however, the "Fire Alarm As-Built" correctly shows the FACP located in an administrative room on the southwest region of the building. See *Appendix J: Fire Alarm System*, *Figure 56* for the FACP location.

The fire alarm system is broken up into zones each with their own Fire Alarm Terminal Cabinet (FATC). The FATCs act as a gathering point for all circuits within the zone. The as-builts incorrectly list FATC's as "Not Applicable" and does not show the FATC's on the drawings.

6.2 Fire Detection Devices

Fire detection devices on a Signaling Line Circuit (SLC) or IDC shall be an NFPA 72 Class A circuit per *Sandia Spec. 13852 Sect. 1.06*. According to *NFPA 72, 12.3.1*, a Class A pathway includes a redundant path, continues to operate past a single open or a single ground fault, and conditions that affect the intended path result in a trouble signal.

The laboratory building contains various forms of fire detection throughout the building. There is no smoke detection required throughout the entire building per IBC 907.2 and NFPA 72, 17.5.3.2. Smoke/Duct detectors exist to specific areas to activate a fire alarm safety function per IBC 907.3. These fire alarm safety functions include controlling door releases, shutting down the HVAC, shutting down toxic gas panel. Smoke detectors are also located to protect the FACP and FATCs per IBC 907.4.1 and NFPA 72, 10.4.4. Duct detectors are located in the supply and return air ducts, and vane-type water flow detectors are located on the sprinkler risers. Heat detectors or specialty harsh environment smoke detectors are used instead of the photoelectric smoke detectors in areas that are smoky, dusty, humid, or have extreme temperatures. A High-Sensitivity Smoke Detection (HSSD) system is also located in the clean room areas. Manual pull stations are located every 400 feet in the corridor, and every 150 feet along the chemical transport route per IBC 415.10.2. Manual pull stations are located near every exit of the building even though IBC 907.2 only requires a minimum of one pull station.

The pull stations are located within 5 feet of every exit per IBC 907.4.2.1. There are two additional pull stations located in the south corridor of the southern region due to the requirements for an H-occupancy per IBC 907.2.5. Manual pull stations are installed 42-48 inches above the finished floor per IBC 907.4.2.2. Below is a table of fire alarm equipment installed in the laboratory building:

Table 20 - Fire Alarm Equipment

Equipment	Make	Model	Location
FACP	EST	QS4-12-R-1	Room 1936
Annunciator	EST	QSA-1-F	Lobby
Manual Pull Station	EST	SIGA-278	Along exit pathways; near exit door
Intelligent Duct Detector	EST	SIGA-SD	Throughout Building
Intelligent Heat Detector	EST	SIGA-HRS	
Intelligent Photoelectric Smoke Detector	EST	SIGA-PS	Throughout Building
Multitone Horn/Strobe	Wheelock	MT-2475W-FR	Occupiable Spaces
Multitone Horn/Strobe Weatherproof	Wheelock	MTWP-2475W-FR	Outside exterior walls
Booster Power Supply	Wheelock	PS1224-8MP	Throughout Building
Multi-Candela Strobe	Wheelock	RSS-24MCW-FR	Occupiable Spaces
Sync Module	Wheelock	SM-24-R	
Surge Suppressor	Edco	FAS-120AC	
Battery (7 Amp Hour)	YUASA	NP7-12	
14/2 NAC Cable	CSC	250017	Throughout Building
16/2 SLIC Data Cable	CSC	250039	Throughout Building

6.3 Location, Spacing, and Placement – Detection Devices

The location and spacing drawings of the fire alarm system can be found in *Appendix K: Fire Alarm System Location and Spacing*. The laboratory building is not a continuously occupied building (24 hours per day, 7 days per week, 365 days per year).

6.4 Alarm, Supervisory, and Trouble Signals

In general, NFPA 72, 26.3.8.1.1 requires the following to result in an alarm signal:

Manual fire alarm boxes
Automatic fire detectors
Waterflow from the automatic sprinkler system
Actuation of other fire suppression systems or equipment

More specifically, Sandia Spec. 13852 Sect. 1.06 D lists the following as initiators for an alarm signal:

Manual pull stations
Heat detectors
Photoelectric smoke detectors
Automatic sprinkler system water flow detection switches
Automatic sprinkler system pressure switches
Air sampling control panels
Fire suppression release panels
UV/IR detectors
Hazard monitoring inputs

The figure below shows the alarm system outputs for various signals received by the FACP:

SYSTEM OUTPUTS

- A – ACTUATE COMMON ALARM VISUAL AND AUDIBLE INDICATOR AT FACP
- B – DISPLAY ALARM DEVICE ADDRESS POINT AND LOCATION DESCRIPTION
- C – ACTUATE SUPERVISORY VISUAL AND AUDIBLE INDICATOR AT FACP
- D – DISPLAY SUPERVISORY DEVICE ADDRESS POINT AND LOCATION DESCRIPTION
- E – ACTUATE COMMON TROUBLE VISUAL AND AUDIBLE INDICATOR AT FACP
- F – DISPLAY TROUBLE CONDITION
- G – TRANSMIT SUPERVISORY SIGNAL TO CENTRAL STATION
- H – TRANSMIT ALARM TO CENTRAL STATION
- I – ACTUATE BUILDING NOTIFICATION DEVICES
- J – TRANSMIT TROUBLE TO CENTRAL STATION
- K – SWITCH HVAC EQUIPMENT CONTROLS TO FIRE ALARM MODE
- L – RELEASE MAGNETICALLY LOCKED DOORS
- M – SILENCE PANEL AND FACILITY AUDIBLES AND VISUALS
- N – CONTROL PANEL RETURNS TO NORMAL (AUDIBLES AND VISUALS STOP)
- O – RECORD EVENT IN FACP SYSTEM MEMORY

	FACP SYSTEM INPUTS		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	
1	MANUAL PULL STATIONS	1	●	●						●	●			●			●	1
2	AREA SMOKE AND HEAT DETECTORS	2	●	●						●	●			●			●	2
3	SPRINKLER WATERFLOW	3	●	●						●	●			●			●	3
4	OPEN CIRCUIT, GROUND FAULT	4					●	●				●					●	4
5	SPRINKLER TAMPER SWITCH / PIV	5			●	●			●									5
6	DUCT DETECTORS	6			●	●			●				●					6
7	NAC POWER SUPPLY TROUBLE CONDITION	7					●	●				●						7
8	DACT FAIL / TELECOM FAIL	8					●	●				●					●	8
9	FIRE ALARM AC POWER FAILURE / ABNORMALITY	9					●	●				●					●	9
10	FIRE ALARM SYSTEM LOW BATTERY / BATTERY CIRCUIT FAIL	10					●	●				●					●	10
11	SYSTEM SILENCE	11					●	●				●			●			11
12	SYSTEM RESET	12														●		12
13	ANCILLARY CONTROL PANELS (HSSD)	13			●	●			●				●					13

Figure 2 - Fire Alarm System Functional Matrix

All alarm signals from the functional matrix above result in transmitting the alarm to the proprietary station. The proprietary station performs the proper signal disposition procedures per *NFPA 72, 26.4.6.6*.

6.5 Alarm Notification Devices

See *Table 20* for a list of notification devices.

The cut sheets from the Wheelock Multitone Horn/Strobe MT-2475W-FR can be found in *Appendix L: Wheelock Horn/Strobe*. The horn/strobe operates at 24 VDC. The horn RMS current is 0.074 Amps when the horn is operating at 92 dBA. When the strobe is operating at 75 cd, the RMS current is 0.060 Amps. These values will be used in *Section 6.7* when calculating power requirements for the secondary power supply. All specifications were taken from the Cooper Industries website.

6.6 Location, Spacing, and Placement – Notification Devices

NFPA 72 Table A.18.4.3 states average ambient sound levels for various occupancies. The laboratory building will primarily fall under the business occupancy with an average ambient sound level of 55 decibels A-weighted (dBA). The mechanical rooms throughout the building will have an assumed sound level of 85 dBA. The total sound

pressure level (SPL) can't exceed 110 dBA per NFPA 72, 18.4.3.1 and the notification appliance (NA) must have a SPL at least 15 dBA above ambient per NFPA 72, 18.4.3.1. This means the mechanical rooms must have a horn with a SPL of 100 dBA $(85\ dBA + 15\ dBA)$, and the rest of the building must have a horn SPL of 70 dBA $(55\ dBA + 15\ dBA)$.

The Wheelock MT Multitone Horn/Strobes has a maximum SPL of 92 dBA at 10 feet. The following table utilizes the "6 dBA Rule" found in the NFPA Handbook Sect. 14-3 to calculate the SPL as you move further away from the horn:

Table 21 - Sound Pressure (6 dBA Rule)

Sound Pressure (dBA)	Distance from Source (ft.)
92	10
86	20
80	40
74	80
68	160

The table above tells us that you can move almost 160 away from a horn before the SPL drops below the minimum required of 70 dBA. The fire alarm drawings shown in *Appendix K: Fire Alarm System Location and Spacing* clearly show all areas in the building (excluding mechanical rooms) area located within 160 feet of a horn. The laboratory building (excluding mechanical rooms) meets the minimum horn SPL criteria required by NFPA 72. The mechanical rooms on the other hand can have an ambient SPL in the 90's. The current horns used are not capable of providing an SPL that is 15 dBA greater than the ambient SPL. Fortunately, strobes exist in the mechanical rooms to provide an additional means of notification per NFPA 72, 18.4.1.1.

The Americans with Disabilities Act (ADA) requires all public and common use areas to have strobes per ADA-ABA 2004, Sect. 215 and Sect. 702. The Wheelock MT Multitone Horn/Strobes have an adjustable strobe setting of 15 cd, 30cd, 75 cd, and 110 cd. The following table provides a maximum room size for each strobe rating. The table is taken from NFPA 72 Table 18.5.5.4.1(a):

Table 22 - Maximum Room Size for One Strobe

Maximum Room Size (ft)	Min. Light Output – One Light per Room (cd)
20 x 20	15
28 x 28	30
45 x 45	75
54 x 54	110

Table 23 - Maximum Room Size for Four Strobes

Maximum Room Size (ft)	Min. Light Output – Four Light per Room (cd)
40 x 40	15
50 x 50	30
80 x 80	75
100 x 100	110

The common areas can be accommodated by a single strobe, however, according to the fire alarm drawings, not all strobes are set to an appropriate candela (cd) setting. The lobby is currently set to 15 cd and should be increase to 30 cd. The North and South outdoor oasis should be increased to 110 cd. All corridor strobes should be increased to 75 cd especially because of the curved design of some of the corridors. The wall mounted appliances are mounted between 80 and 96 inches above the finished floor to meet the requirements of NFPA 72, 18.5.5.1.

6.7 Power Requirements

The battery must be sized to provide enough power to run the fire alarm system for 24 hours in supervisory mode and 5 minutes in alarm mode per NFPA 72, 10.6.7.2.1. Below are the calculations for the four power supplies located throughout the building:

Table 24 - Power Requirements

POWER SUPPLY 1					
Item	Alarm Current (A)	Time Factor (hr)	Alarm Amphours	20% Safety Factor	Total Amphours
NAC 1	0.903	0.083	0.075	0.015	0.090
NAC 2	0.627	0.083	0.052	0.010	0.062
NAC 3	1.044	0.083	0.087	0.017	0.104
FACU	0.075	0.083	0.006	0.001	0.007
Item	Standby Current (A)	Time Factor (hr)	Standby Amphours	20% Safety Factor	Total Amphours
FACU	0.075	24	1.8	0.36	2.16
				TOTAL	**2.424**

POWER SUPPLY 2					
Item	Alarm Current (A)	Time Factor (hr)	Alarm Amphours	20% Safety Factor	Total Amphours
NAC 1	0.42	0.083	0.035	0.007	0.042
NAC 2	0.64	0.083	0.053	0.011	0.064
NAC 3	0.32	0.083	0.027	0.005	0.032
NAC 4	0.32	0.083	0.027	0.005	0.032
FACU	0.075	0.083	0.006	0.001	0.007
Item	Standby Current (A)	Time Factor (hr)	Standby Amphours	20% Safety Factor	Total Amphours
FACU	0.075	24	1.8	0.36	2.16
				TOTAL	**2.337**

POWER SUPPLY 3					
Item	Alarm Current (A)	Time Factor (hr)	Alarm Amphours	20% Safety Factor	Total Amphours
NAC 1	1.088	0.083	0.090	0.018	0.108
NAC 2	1.14	0.083	0.095	0.019	0.114
NAC 3	1.184	0.083	0.098	0.020	0.118
FACU	0.075	0.083	0.006	0.001	0.007
Item	Standby Current (A)	Time Factor (hr)	Standby Amphours	20% Safety Factor	Total Amphours
FACU	0.075	24	1.8	0.36	2.16
				TOTAL	**2.507**

POWER SUPPLY 4					
Item	Alarm Current (A)	Time Factor (hr)	Alarm Amphours	20% Safety Factor	Total Amphours
NAC 1	0.334	0.083	0.028	0.006	0.033
NAC 2	0.42	0.083	0.035	0.007	0.042
NAC 3	1.031	0.083	0.086	0.017	0.103
FACU	0.075	0.083	0.006	0.001	0.007
Item	Standby Current (A)	Time Factor (hr)	Standby Amphours	20% Safety Factor	Total Amphours
FACU	0.075	24	1.8	0.36	2.16
				TOTAL	**2.345**

Each power supply is furnished with two, 7 Ah batteries, which are more than adequate according to the calculated battery requirements above.

6.8 Inspection, Testing, and Maintenance – Fire Alarm System

The current ITM requirements for fire alarm systems are applicable to both new and existing systems per NFPA 14.1.4. The service personnel performing the ITM on a system is required to be experienced and qualified per NFPA 72, 14.2.3.6. A test plan shall describe the scope of the testing and shall be provided to the service personnel prior to testing per NFPA 72, 14.2.10.1.

NFPA 72 Table 14.3.1 provides a table to determine what components need to be visually inspected and how often. NFPA 72 Table 14.4.3.2 provides a similar table, but with testing requirements. Table 14.4.3.2 also provides the method for testing the components. All equipment shall be maintained in accordance with the manufacturer's instructions per NFPA 72, 14.5.1. The frequency of maintenance is determined by the type of equipment and the local ambient conditions per NFPA 72, 14.5.1.

Sandia utilizes a program called Maximo to ensure all ITM requirements are met.

Table 25 - Fire Alarm ITM

Component	Visually Inspect	Test
All Equipment	Annual [72:14.3.4]	Initial Acceptance
Trouble Signals	Semiannual	Annual
DACT	Annual	Annual
Batteries (Sealed Lead-Acid)	Semiannual [72:10.6.10]	Annual
Remote Annunciator	Semiannual	Annual
Remote Power Supplies	Annual [72:10.6]	Annual
Air Sampling	Semiannual [72:17.7.3.6]	Annual
Duct Detector	Semiannual [72:17.7.5.5]	Annual
Fire Extinguishing System Switches	Semiannual	Annual
Manual Fire Alarm Boxes	Semiannual	Annual
Heat Detectors	Semiannual	Annual
Smoke Detectors	Semiannual	Annual; Sensitivity Testing [72:14.4.4.3]
Supervisory Signal Devices	Quarterly	Annual
Waterflow Devices	Quarterly	Annual (electric); Semiannual (mechanical)
Audible Appliances	Semiannual	Annual
Visible Appliances	Semiannual [72:18.5.5]	Annual

7.0 STRUCTURAL FIRE PROTECTION

7.1 Structural Fire Protection Classification

The laboratory building is constructed entirely of Type II-B noncombustible materials per DOE Order 420.1. The building is located on a 20 acre lot with no surrounding buildings. This allows the building to maximize the allowable area increases found in IBC 506.

7.2 Construction Classification

In this section we will compare the actual building area to the tabulated building areas. We will also determine the allowable area increase due to frontage and sprinkler increase factors according to IBC 506.

The laboratory building is a single story building with a few mechanical penthouses. The penthouses are not occupied; therefor the building will be treated as a one story building for the sake of calculating the allowable building area. The following table list tabulated values for actual areas by occupancy type.

Table 26 - Actual Floor Areas

Occupancy	Actual Area 1st Floor (ft^2)	Actual Area Total Building (ft^2)
B	62,512	69,996
A-3	2,104	2,104
F-1	8,085	8,085
H-3	711	711
H-5	9088	16,398
TOTAL	82500	97294

The building has an unusual shape which will be approximated as a rectangle for the sake of calculating the allowable area increase. The following rectangular dimensions give an approximate area of $82{,}500\ ft^2$:

$$Approx.Building\ Area = 254\ ft \times 325\ ft = 82550\ ft^2$$

Section 506 of the IBC contains many equations used for calculating the allowable area increase. The main equation used to calculate area increase is IBC 506.1 Eq. 5-1:

$$A_a = \{A_t + [A_t \times I_f] + [A_t \times I_s]\}$$

Where:

$$A_a = allowable\ building\ area\ per\ story\ (ft^2)$$

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

$$I_f = Area\ increase\ factor\ due\ to\ frontage\ (Sect.\ 506.2)$$

$$I_s = Area\ increase\ factor\ due\ to\ sprinkler\ protection\ (Sect.\ 506.3)$$

Below is the calculation for I_f taken from IBC 506.2 Eq. 5-2. The entire perimeter is surrounded by a width of open space greater than 30 feet:

$$I_f = \left[\frac{F}{P} - 0.25\right]\frac{W}{30}$$

$$P = 2(254\ ft) + 2(325\ ft) = 1158\ ft$$

$$F = P\ (due\ to\ open\ space\ width\ greater\ than\ 20\ ft)$$

$$W = \frac{30(P)}{F} = \frac{30(1158)}{1158} = 30\ ft$$

$$I_f = \left[\frac{1158}{1158} - 0.25\right]\frac{30}{30} = \boxed{0.75}$$

Certain occupancies meet the exception contained within IBC 506.2.1 which permits their width of public way (W) to be increased to a maximum of 60 feet which gives them the following frontage increase factor:

$$I_f = [1 - 0.25]\frac{60}{30} = \boxed{1.5}$$

IBC 506.3 permits an increase of 300 percent for sprinklered buildings with only story above grade, therefore:

$$I_s = \boxed{3}$$

The following spreadsheet takes the area increase factors calculated above, and determines the allowable area increase for each occupancy type:

Table 27 - Allowable Area Increase

Occupancy	$A_{act}\ (ft^2)$	$A_t\ (ft^2)$	I_f*	I_s	$A_a\ (ft^2)$	Ratio
B**	62,512	23,000	1.5	3	126,500	0.49
A-3***	2,104	9,500	1.5	3	52,250	0.04
F-1**	8,085	15,500	1.5	3	85,250	0.09
H-3****	711	14,000	1.5	0†	35,000	0.02
H-5	9,088	23,000	0.75	3	109,250	0.08
SUM						**0.72**

**506.2.1 – Where building meets IBC 507, width of public way is limited to a max of 60*
**507.3 – Considered an unlimited area building*
***507.6 – Considered an unlimited area building*
****507.8 – Considered an unlimited area building*
†506.3 Exception – No sprinkler increase permitted

All occupancies except for Occupancy B complied with their tabulated areas IBC Table 503 prior to the allowable area increase. Occupancy B did not originally comply with its tabulated value, but is in compliance after the allowable area increase calculation. The last column of *Table 27* above meets IBC 508.4.2 which states for separated occupancies, the sum of the ratios of the actual area divided by the allowable area must be less than 1.

7.3 Construction Material Fire Resistance Requirements

A Type II-B building requires the use of noncombustible materials. The laboratory building is constructed of steel decks, steel bar joists, steel wide flange beams, and steel columns. IBC Table 602 discusses the fire resistance rating for various building elements based on the construction type. For a type II-B construction, no elements require a fire-resistance rating, including the primary structure, load bearing walls, interior nonbearing walls, floor construction, and roof construction.

IBC Table 602 shows the rating requirements for exterior nonbearing walls. The laboratory building has a fire separation distance greater than 30 feet on all sides, therefore, the exterior nonbearing walls don't require a fire resistance rating.

7.4 Occupancy Separation

The laboratory building does not require fire protection on the building elements except for those that are part of a fire barrier. A previous version of the IBC required the laboratory building to use the occupancy separation requirements in *Table 28*. These separation requirements take into account the reduced values allowed by automatic sprinkler systems. Table 29 shows the separation requirements for the current IBC (2012):

Table 28 - Required Sepatation (IBC - Older Version)

USE	A-3	B	F-1	H-3	H-5
A-3		1	2	3*	4*
B			2	1	1
F-1				1	1
H-3					1

**These uses are not adjacent. They accomplish the required separation through the location of multiple rated walls.*

Table 29 - Required Separation (IBC 508.4 - 2012)

USE	A-3	B	F-1	H-3	H-5
A-3		1	1	2	2
B				1	1
F-1				1	1
H-3					1

The older separation requirements were more stringent; therefore, the building exceeds the current code.

IBC 707.5 requires the fire barriers to extend from the top of the foundation to the underside of the floor or roof sheathing. IBC 707.6 limits the size of an opening in a fire barrier, however, the entire building is sprinklered therefore the openings are not limited to 156 square feet per Exception 1. Openings in the fire barrier shall be protected in accordance with IBC 716. Penetrations in the fire barrier shall be protected in accordance with IBC 714. Joints in the fire barrier shall comply with IBC 715.

7.4.1 Fire Barrier - Column Fire Resistance Calculations

The laboratory building is constructed as a Type II-B building and does not require resistance on the structural columns.

7.5 Prescriptive-Based Analysis Conclusion

Based on analysis, the laboratory building meets the prescriptive requirements of the IBC. The hydraulic calculations will need to be run through a computer model, such as AutoSprink, in order to verify the difference between the hand calculations and the contractor’s calculations.

8.0 PERFORMANCE-BASED ANALYSIS

8.1 Disclaimer

The following performance-based analysis uses hypothetical scenarios to analyze the building for life safety. The scenarios are intended to be representative of hazards that exist in laboratory buildings in general. The scenarios are not intended to identify the size and location of actual hazards. Names and identifying details of the laboratory building have been modified to protect the privacy of Sandia. The information in this report is meant to supplement frequent inspections of the building fire protection system and good housekeeping habits in order to maintain the optimum level of safety for the occupants and the building. The fire hazards, calculation assumptions, and pass/fail criteria used for each scenario are conservative in order to provide a factor of safety to the occupants.

8.2 Executive Summary

A comprehensive performance-based analysis was performed on the laboratory building in order to ensure the safety of the occupants and the preservation of the equipment and facilities. The prescriptive-based analysis ensures life safety by determining if the building meets all applicable code requirements. The performance-based design also ensures life safety; however, it accomplishes this by applying appropriate fire scenarios to the building and running an analysis to determine if the occupants have enough time to escape the building before conditions become untenable.

Based on the analysis, the laboratory building did not pass any of the three design scenarios; however, recommendations were offered for each scenario in order to maintain a safe egress for the occupants.

8.3 Introduction to Performance-Based Design

The performance-based analysis is another way of determining the life safety of a particular building. The prescriptive-based analysis strictly follows the code which leaves very little room for flexibility. A performance-based analysis must continue to meet the goal and objectives of the code; however, it provides alternatives to how the code can be achieved. With more flexibility also comes more risk of human error by poor module design, inappropriate equivalencies, and incorrect calculations. Designing a proper performance-based analysis requires appropriate interpretation of the goals, objectives, level of safety, appropriate fire scenarios, assumptions, and safety factors.

A performance-based design can be used to prove an equivalent level of safety if a specific building code was not met, or the building contains an unusual trait that is not typically covered by the building code. A performance-based analysis requires special consideration when choosing fire scenarios and their respective performance criteria. The fire scenarios must accurately represent fire hazards that can potentially occur in the building. The performance criteria must be set to an appropriate threshold in order to ensure life safety while not being too stringent to make the fire scenarios impossible

to pass. The fire protection engineer should state all assumptions and references in order to give the AHJ confidence in the analysis.

8.4 Codes and References

SFPE Engineering Guide to Performance-Based Fire Protection, 2^{nd} Edition
SFPE Handbook of FPE, 4^{th} Edition (SFPE HB)
2012 Edition, NFPA 101 Life Safety Code (LSC): Chapter 5

8.5 Facility Description

The unique building characteristics to the laboratory building will be highlighted in order to determine the most appropriate fire scenarios. The laboratory building is a multi-program laboratory where various research efforts are being conducted throughout the building. The building is composed of office space and laboratory space with a portion of the building dedicated to high hazard use. The laboratories will contain small amounts of chemicals which will be stored in flammable liquid storage cabinets when not in use. The IBC limits the amount of hazardous chemicals that can be used or stored in a control area. The maximum allowable quantities (MAQs) for each material type are listed in IBC Table 307.1(1). The two blocks of lab space contain a 1-hour fire barrier on their perimeter which allows them to be considered a separate control area. The areas of the building that exceed the MAQ limits are considered high hazard occupancies.

The building contains major hallways that run the entire length of the building. The hallways serve as the main exit path for all the occupants in the building. The laboratory building contains two open lobby/collaboration areas connected to the major hallways.

The reminder of the building is dedicated to office use. The east side of the building contains numerous single-occupant hard offices, whereas the west end contains large rooms filled with small cubicle spaces.

8.6 Project Scope

The performance-based analysis will consist of ensuring the fire protection systems for the laboratory building will perform through three fire scenarios. The systems must protect all occupants to safe egress and prevent the fire from spreading beyond the room of origin. The primary stakeholders are the building owner, the AHJ (DOE), the Building and Fire Safety (BFS) department, the tenants, the building operations and maintenance, and the emergency responders.

The fire scenarios are chosen based on the building and occupant characteristics. The performance criteria are established from the design goals and objectives. The RSET is calculated using the method outline in the SFPE handbook as well as the use of the egress computer model Pathfinder. The fire scenarios will be modeled using the fire dynamic simulator FDS.

8.7 Fire Protection Goals

The SFPE Engineering Guide to Performance Based Design and the stakeholders' objectives were used to define the goals of the design project:

1. Life Safety: Minimize fire-related injuries and prevent undue loss of life
2. Property Protection: Minimize fire-related damage to the building and its contents
3. Mission Continuity: Minimize undue loss of operations and business-related revenue due to fire-related damage.

The goals are intended to be broad statements about how a building is supposed to perform under a fire scenario.

8.8 Stakeholder and Design Objectives

The stakeholders' objectives are intended to describe the maximum level of damage that would be tolerable. After the stakeholder's objectives have been determined, it is necessary to create design objectives by determining what aspects of the building need to be protected. The design objective includes acceptable fire conditions that need to be maintained in order to meet the stakeholders' objectives.

Stakeholder's Objectives:

1. Life Safety: Allow safe egress for all occupants outside the room of origin
2. Property Protection: Prevent thermal damage
3. Mission Continuity: Minimize smoke spread

Design Objectives:

1. Life Safety: Maintain tenable conditions
2. Property Protection: Prevent flashover
3. Mission Continuity: Prevent fire from spreading outside the room of origin

8.9 Tenability Criteria

The three major fire hazards associate with untenable conditions are smoke, heat, and toxicity from smoke products. We will discuss in detail each hazard and how they contribute quantifiable performance criteria to the design objectives.

8.9.1 Visibility

Visibility is indirectly proportional to the smoke density (extinction coefficient) and directly proportional to emitted light that reaches the human eye. The following is an equation for visibility determined by T. Jin for light emitting and light reflecting exit signs [1]:

$$V = \frac{8}{C_s}\ (m) \qquad for\ a\ light\ emitting\ sign$$

$$V = \frac{3}{C_s}(m) \qquad \textit{for a light reflecting sign}$$

Where C_s is the smoke density (extinction coefficient) in units of 1/m.

A light emitting sign produces a higher intensity of light than a reflecting sign. This analysis will use the visibility equation for a light reflecting sign to produce more conservative results. The light reflectance value in FDS will be set to 3. The results of Jin's equation are shown in *Figure 3* below. The results show the inverse relationship between visibility and smoke density.

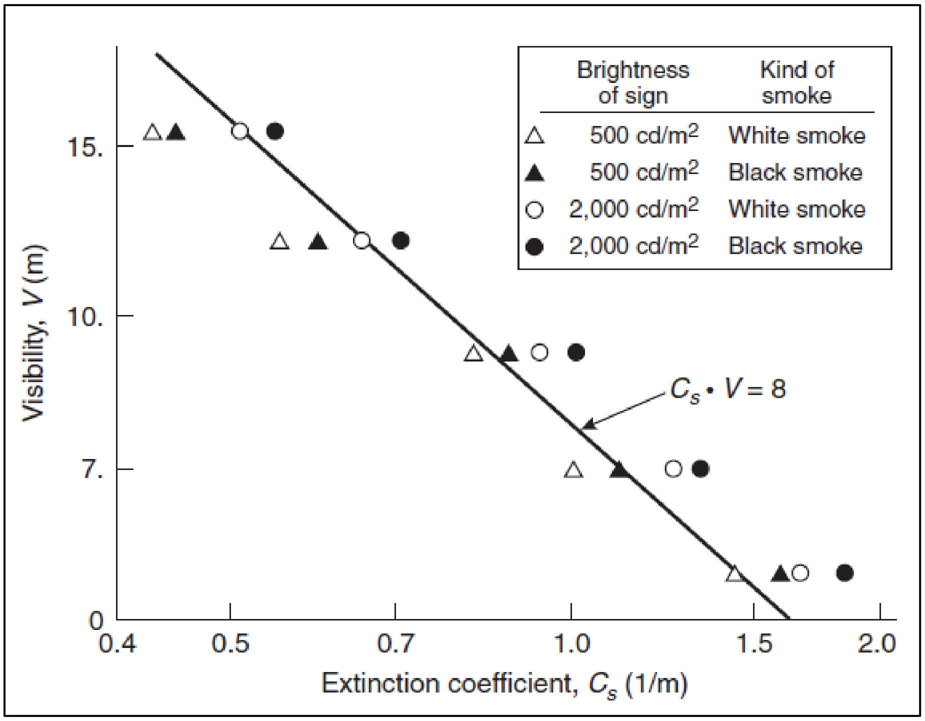

Figure 3 - Smoke Density vs. Visibility of Light Emitting Sign

Numerous visibility tests have been performed by researchers in the fire protection community in order to determine the most appropriate visibility distance for a performance criterion. A brief description of these tests can be found in the SFPE Handbook 4th Edition, Section 2-4. Test criteria posed by fire researchers varies from 1.2 meters to 13.5 meters as shown in Table 2-4.3 The Fire Research Institute conducted a test [2] which required the subjects to insert a pin into different holes of decreasing size as the room filled with smoke. The test equipment was able to record every time the pin contacted the rim of the hole. A second test [3] was conducted by T. Jin and T. Yamada where they required subjects to solve math problems as they walked down a corridor filled with smoke. The end of the corridor also contained heaters which radiated heat towards the subjects. A similar pattern appeared in both of these tests. The initial cause of panic in the smoke filled room was the physical irritation to the eyes, throat, and nose. After the subjects became conditioned to the physical discomfort, their performance in the smoke increased. Finally, the performance decreased a final time when the subjects succumbed to the psychological fear of not knowing what was

going to happen next. This psychological fear was brought on by increased smoke, walking further into the corridor, and experiencing a heating sensation (from the electric heaters). People who are unfamiliar with the rooms performed worse than those familiar with it. For our tenability requirements, we will take a conservative approach and assume that the room will contain people who are unfamiliar with the room. We will use a visibility criterion of *13 meters* found in SFPE Handbook Table 2-4.2. The NFPA Fire Protection Handbook Sect. 3-11 states in most cases, visibility is the tenability criterion that dominates the hazard analysis.

8.9.2 Smoke Layer

The smoke layer is directly related to visibility, toxicity, and upper layer temperature. If the smoke layer is maintained above a specified height, the occupants can safely egress without interference from the smoke harmful effects. We will take our smoke layer height criterion from the IBC 909.8.1 which requires the smoke layer height to be maintained *1.83 meters (6 feet)* above the highest occupied level.

8.9.3 Toxicity

Carbon monoxide is considered the most important asphyxiant gas. This concept is demonstrated by the Strathclyde pathology study [4]. It has the ability to mix with hemoglobin in the bloodstream and create the oxygen reducing toxin, carboxyhemoglobin (COHb). Carbon monoxide is always present in fires, it causes confusion and loss of consciousness, and it is the most common cause of death in fires. Loss of consciousness typically occurs at COHb levels of 40 percent, but can occur at levels as low as 30 percent. The following figure taken from SFPE HB Fig. 2-6.5 represent the time to incapacitation in active monkeys [5] [6]. At a concentration of 1000 ppm CO and 2000 ppm CO, the time to incapacitation was approximately 27 minutes and 14 minutes respectively.

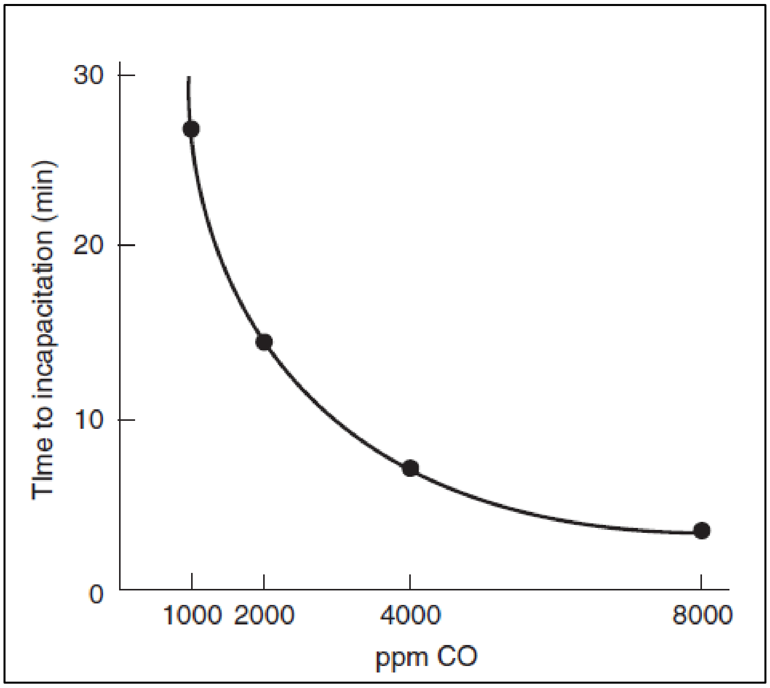

Figure 4 - CO Concentration vs. Time to Incapacitation

One of the most important variables related to CO uptake is the respiratory minute volume (RMV). When respiration data [7] is combined with the Coburn-Forster-Kane equation [8] [9] (which accounts for the CO uptake and excretion through the lungs) a predictive time to incapacitation can be created based on various RMV values. This predictive model is graphed in *Figure 5*, taken from SFPE HB Fig. 2-6.14. The model calculates time to incapacitation for a 70 kg human at various respiratory minute volumes (RMV) in L/min. Curve A represent an RMV of 8.5 L/min (resting), curve B in an RMV of 25 L/min (light work), and curve C is an RMV of 50 L/min (heavy work). At 1000 ppm CO (0.1 % CO), incapacitation occurs in 35 minutes on curve B and 17 minutes on curve C.

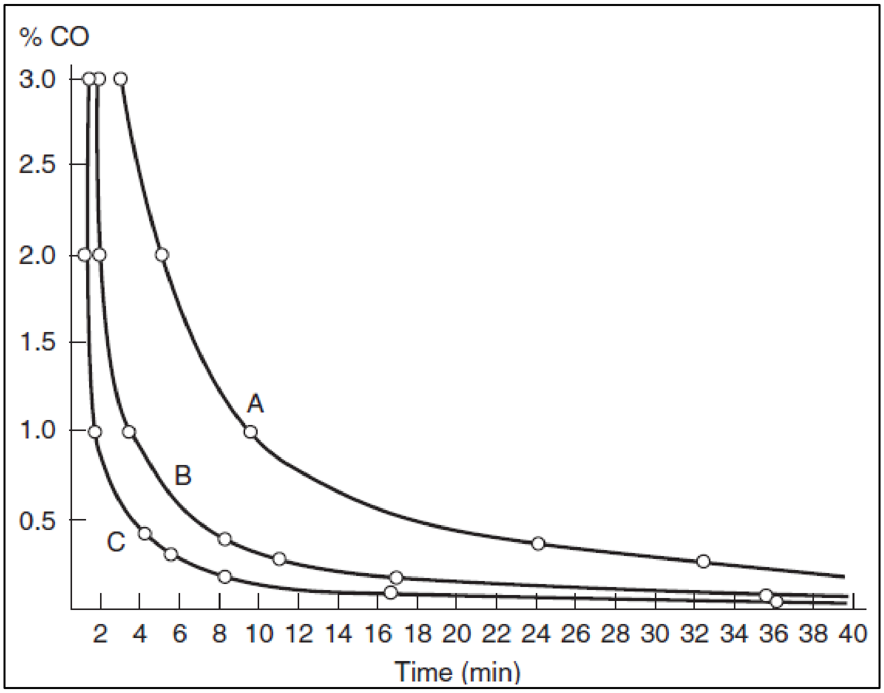

Figure 5 - Time to Incapacitation for 70 kg human at different levels of activity

Typically a CO concentration criterion of 2000 ppm is acceptable; however, due to the unknown size of occupants as well as their fitness level (pertaining to RMV) and familiarity of the facility, we will choose a more conservative criterion of 1000 ppm CO for our analysis.

8.9.4 Temperature

Room temperature can affect an occupant in three different ways. Elevated temperatures can lead to hyperthermia (heat stroke), skin burns, and respiratory tract burns. W.V. Blockley conducted some research [10] where he determined room temperature tenability for humans is limited by skin burns for temperatures great than 120 C and hyperthermia for temperatures less than 120 C (dry air). Hyperthermia is defined as a prolonged exposure to heat which raises the core body temperature causing blurred consciousness, illness, and eventually death. The threshold for all of these harmful effects is magnified by air saturation. Heat is most harmful in 100 percent saturated air because it prevents our sweat from evaporating and cooling ourselves. We will assume saturated air for our analysis due to the water produced by the fire as well as the activation of sprinklers. The SFPE Handbook Figure 2-6.27 adapts the research conducted by Blockley:

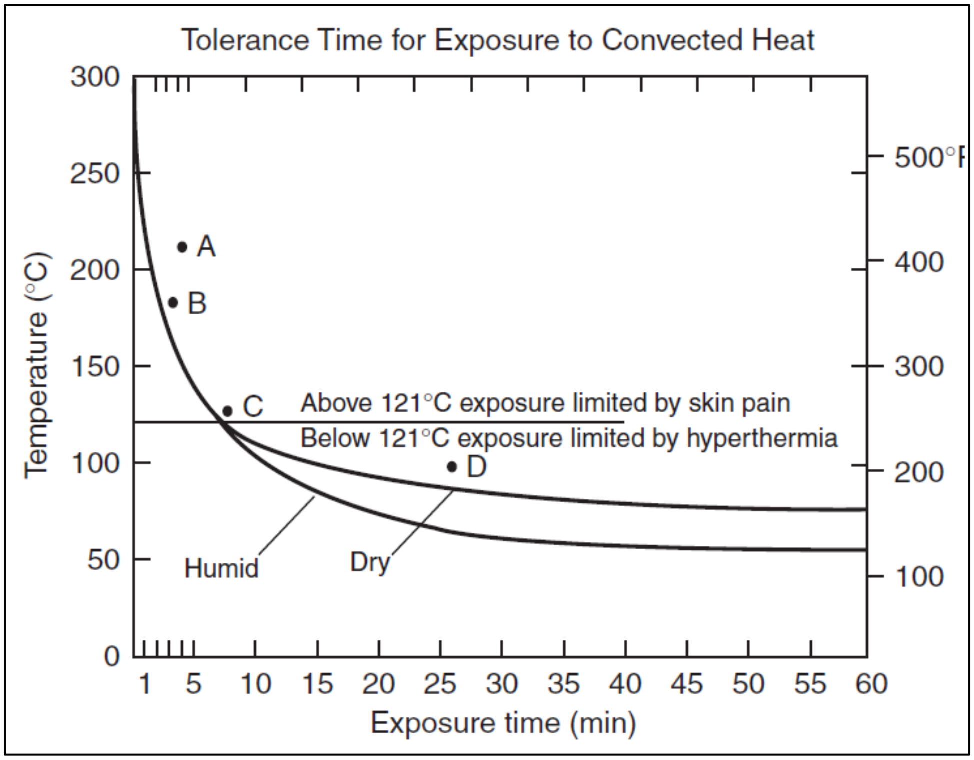

Figure 6 - Thermal Tolerance for Humans

Judging by the figure above, a tenable egress is feasible as long as the temperature stays below 60 C. We will use a temperature criterion of *60 C*.

8.9.5 Flashover

Room flashover is associated with fire and smoke spread outside the room of origin. When flashover occurs, the room integrity is compromised and the fire and smoke will no longer be contained to the room of origin. This is especially important due to the open corridors that run the entire length of the building. If smoke were to spread from a room to the corridor, major egress paths could be compromised. Also, smoke spread could impact the functionality of highly sensitive test equipment in various laboratories. SFPE HB Sect. 3-6 describes how research [11] conducted by Thomas indicates the onset of flashover is typically represented by an upper gas layer of 500-600 C. We will use the upper layer temperature of *500 C* for our flashover criterion.

8.9.6 Performance Criteria Summary

Below is a table summarizing fire protection goals, design objectives, and their respective performance criteria:

Table 30 - Goals, Objectives, and Criteria

Fire Protection Goal	Stakeholder Objective	Design Objective	Performance Criteria
Minimize fire-related injuries	Allow safe egress for all occupants outside the room of origin	Maintain tenable conditions	Visibility > 13 m
			Smoke Layer Height > 1.83 m
			CO < 1000 ppm
			Room Temperature < 60 C
Minimize fire-related damage to the buildings and its contents	Prevent thermal damage	Prevent Flashover	Upper Layer Temperature < 500 C
Minimize undue loss of operations	Minimize smoke spread	Prevent fire and smoke from spreading outside the room of origin	Upper Layer Temperature < 500 C

8.10 Egress Analysis

8.10.1 Egress Analysis Introduction

In this section we will layout the information necessary to calculate the total egress time. This section will not contain any egress calculations. The fire scenarios found in Section 8.11 of this report will contain their own egress analyses for their respective occupant loads and exit layouts. An egress analysis is used to calculate the RSET. The RSET is how long it will take for the occupants to exit the building. The RSET includes detection time, alarm time, pre-movement time, and travel time. The RSET is then compared to the ASET in order to determine if occupant have enough time to safely exit the facility. The ASET is calculated by modeling fire scenarios and determining when they exceed the performance criteria. The ASET must be greater than the RSET in order for a safe egress to occur. If the ASET is less than the RSET, the building fails the fire scenario and corrective actions will be recommended to increase the ASET. The following figure taken from NFPA HB Fig. 3.11.4 portrays the RSET vs. ASET calculations.

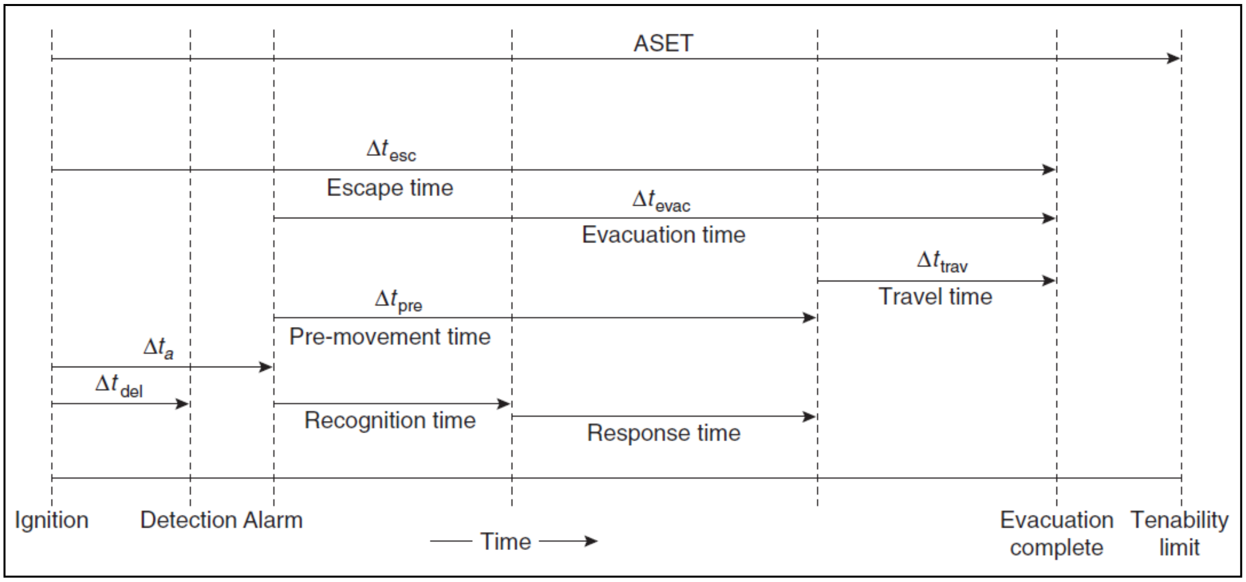

Figure 7 - Timeline for ASET vs. RSET

8.10.2 Characteristic of Occupants

Table 31 - Characteristic of Occupants

Characteristics	Description
Population	The laboratory building is designed to have a total occupant load of 972.
Alertness	Work is only performed in the building during regular business hours and there are no resting/lodging areas within the facility. The occupants will be awake.
Responsiveness	Due to the lab work taking place in the laboratory building, occupants may be used to unusual smells which could make detection more difficult.
Commitment	SNL trains its employees quarterly and annually on the importance of safety in the workplace. SNL employees are thoroughly committed to all safety activities
Focal Point	The occupants' attention is drawn to the work on their desk or their lab bench.
Physical/Mental Capabilities	SNL trains its employees to be aware of the cues related to life safety.
Role	There is a good blend of leaders and followers, but people may attempt to lead more at work in order to stand out to their supervisor.
Familiarity	The laboratory building is not open to the public, therefore, only approved occupants are allowed in the building. The laboratory is a guest research facility and may contain occupants who are new to the facility. Not all occupants may be familiar with the layout of the building.
Social Affiliation	The population of office employees work better as a group than the population of lab employees due to the nature of their daily seating arrangement and close interaction with numerous coworkers.
Condition	The physical condition of occupants is at or slightly above average. The occupants won't be required to traverse stairs during their egress from the 1 story building.
Gender	Composed of a good mix of male and female.
Age	The population is mostly composed of young and middle aged adults.

8.10.3 Egress Calculation Method

The following steps will be used to calculate the egress time for each fire scenario:

Determine the occupant load for the room or building (P)
Determine the number of available exit doors from the room or building (D)
Determine effective width of each door (W_e)
Determine the specific flow of each door (F_s)
Calculate the flow capacity of each door (F_c)
Calculate the time of passage through all available doors (t_p)
Determine the pre-movement time (t_{p-e})
Calculate the detection time (t_d)
Calculate the escape time (t_{esc})

8.10.4 Egress Assumptions

All occupants start egress at the same time. Queuing will occur at the doors to the outside therefore the specific flow, F_s, will be the maximum specific flow, F_{sm}. The speed of movement and the travel time will not be calculated due to the assumption of queuing. The population will use all facilities in the optimum balance. None of the private exits will be considered.

8.10.5 Pre-Movement / Movement Plan

The Pre-movement time is the time from when an occupant decides to leave to the time they actually begin egress movement. Occupants may contribute to their pre-movement times by doing the following activities before leaving:

- Retrieving Keys
- Putting on jacket and additional outerwear (in winter)
- Saving data on computer
- Locking/shutting down computers
- Shutting off experiments
- Safely storing chemicals
- Powering down lab equipment
- Notifying coworkers of need to evacuate
- New employees or guests looking for guidance on where to go
- Retrieving cell phone from lock box at entrance of building.

8.11 Fire Scenarios

Careful consideration must be taken to ensure appropriate fire scenarios are chosen for the building to be analyzed. The following table highlights fire scenarios taken from various sources. The table was used to determine the most appropriate scenarios for the laboratory building:

Table 32 - Design Fire Scenarios

NFPA 101; 5.5.3 Scenarios	Common Scenarios	Building Characteristics
Occupancy-Specific Fire	Intentionally set fire	Visitors
Ultrafast-developing fire in primary means of egress	Electrical malfunction	Chemical Storage
Normally unoccupied room	Smoking	Cleanroom
Concealed space next to large occupied room	Equipment	Located off-site (response time)
Slowly developing fire, shielded from fire protection	Carelessness	
Most Severe Fire	Heating	
Outside Exposure	Cooking	
Ordinary combustibles; fire protection ineffective		

The first column of the table pulls the eight required design fire scenarios from the LSC Sect. 5.5.3. The second column pulls common scenarios from NFPA 805 and the "Fire in the US" report [12] by FEMA. The third column considers building characteristics that could potentially play a significant role in a fire scenario.

8.11.1 Design Fire Scenario 1: Lobby – Electrical Fire

The first fire scenario is a fire containing computer equipment and a polyurethane chair. The fire occurs in a collaboration room adjoining the corridor.

Figure 8 – Fire Scenario 1 (Location)

The room is filled with a few moveable tables and chairs as well as a single computer station. The area is open to the corridor with decorative wooden slats separating the two spaces (See the figure directly below for a picture of the room). Typically a room is not allowed to open up to the corridor, but IBC 1018.6 permits corridor continuity for a lobby, foyer, or reception room open to the corridor as long as the room maintains the same fire rating as the corridor. The corridors are considered B occupancy and don't require a fire-resistance rating per IBC Table 1018.1. The collaboration area is used like a lobby to meet up with colleges or complete a quick task on the computer. The collaboration area is not intended to be normally occupied. Due to the transient nature of the collaboration area, we will assume it to be used like a lobby.

Figure 9 - Collaboration Area/Lobby

The image below shows a picture of the computer work station. The printer is assumed to be the ignition source with the keyboard, monitor, desktop tower, and black cushioned office chair all acting as secondary ignition items.

Figure 10 - Lobby Computer Station

For this scenario we will assume that water supply was accidently left off after routine testing, thus rendering the sprinkler system ineffective (LSC 5.5.3 (8)). This scenario will take a close look at the hazard associated with having an open room adjoining the major egress corridor that runs the entire length and width of the building.

8.11.1.1 *Scenario 1: Heat Release Rates*

The following HRR graphs were taken from the SFPE HB Section 3-1. The graphs show the HRR curve for an upholster chair, a monitor, a printer, and a keyboard. The

HRR curves all have a growth rate of approximately 300 seconds. The table below shows the sum of their peak HRR is 300 kW. The FDS model will have a fire growth of 300 seconds to 300 kW and then the HRR curve will level out at 300 kW for the remainder of the analysis.

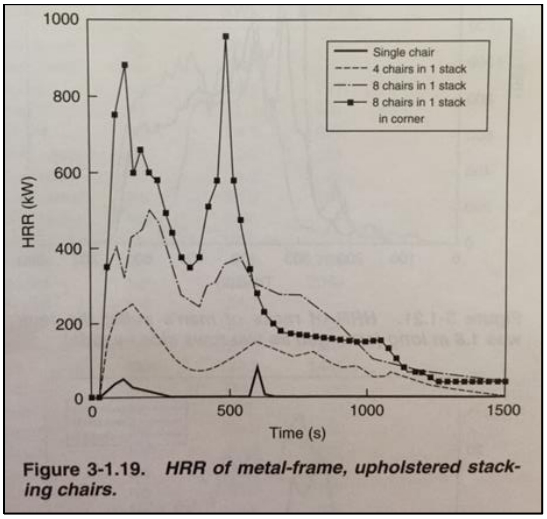

Figure 11 - HRR Upholstered Chair [13]

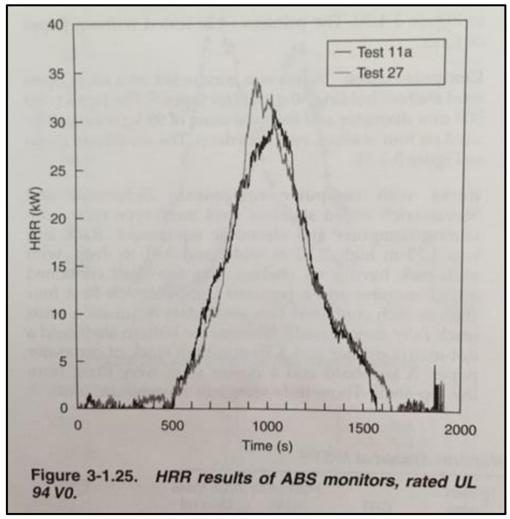

Figure 13 - HRR Monitor [15]

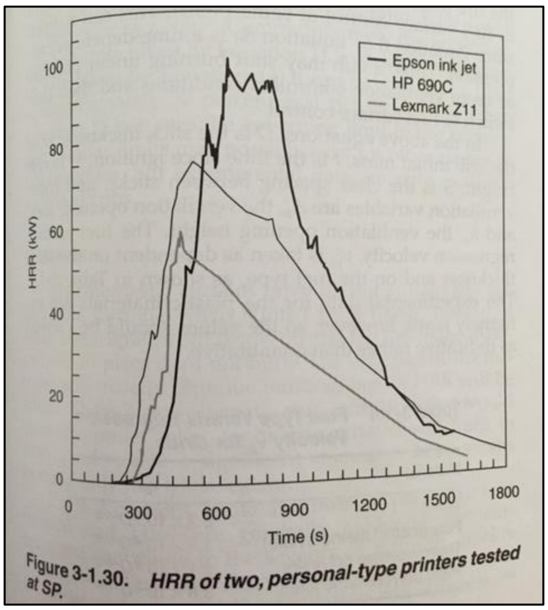

Figure 12 - HRR Printer [14]

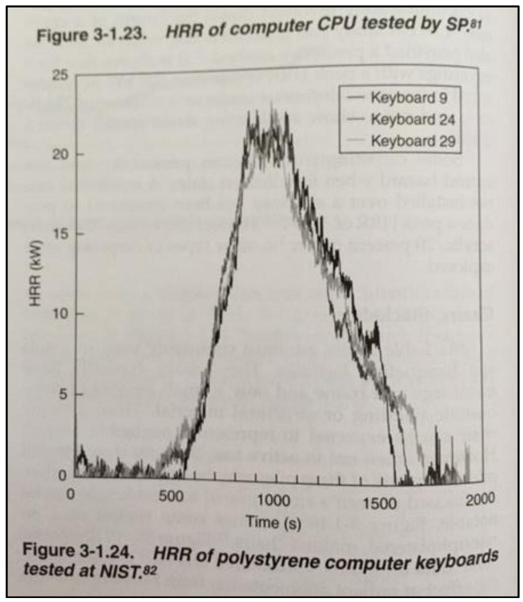

Figure 14 - HRR Keyboard [15]

Table 33 - Lobby Peak HRR

ITEM	PEAK HRR (kW)
Keyboard	23
Monitor	35
Desktop Tower	35
Printer	100
Chair	100
TOTAL	**293**

8.11.1.2 *Scenario 1: Egress Analysis (Evacuation Time, t_e)*

The following tables show the egress calculations for the entire population of the laboratory building to egress out of the five major exits. The entire population was chosen from this scenario because of the location of the fire and the impact the smoke in the major corridor poses on the escape route for all occupants.

Table 34 - Flow Capacity of Doorway

Flow Capacity of a Doorway	
Effective Width (SFPE HB Table 3-13.1 Boundary Layer)	$W_e = 64" - 12" = 52" = 4.33'$
Maximum Specific Flow (SFPE HB Table 3-13.5	$F_{sm} = 24.0\ persons/min/ft$
Calculated Flow Capacity (SFPE HB 3-13, Eq. 8)	$F_c = F_s W_e = (24)(4.33) = \mathbf{103.92\ person/door/min}$

Table 35 - Estimated Speed of Movement Through Doorway

Estimate Speed of Movement Through Doorway	
Population Density (SFPE HB Figure 3-13.8, evaluated at F_{sm})	$D = 0.175\ persons/ft^2$
Evacuation Speed Constants (SFPE HB Table 3-13.2)	$k = 275\ ft/min$ $a = 2.86\ ft^2/person$
Speed of Travel (SFPE HB 3-13, Eq. 5)	$S = k - akD = 275 - (2.86)(275)(0.175) = \mathbf{137.4\ ft/min}$

Table 36 - Time of Passage Through Doorways

Time of Passage Through Doorways	
Population (SFPE HB 3-13, Eq. 10)	$P = 972\ persons$
Time of Passage (SFPE HB 3-13, Eq. 10)	$t_p = P/F_c$ $= \frac{972\ persons}{5\ doors \times 103.92\ persons/door/min}$ $= \mathbf{112}\ sec$

The evacuation time is 112.2 seconds (1.87 minutes). The SFPE HB 3-13, Eq. 2 equates the total escape time to the pre-evacuation time plus the evacuation time:

$$t_{esc} = t_{p-e} + t_e$$

8.11.1.3 *Scenario 1: Egress Analysis (Pre-Movement Time, t_{p-e})*

The SFPE HB Sect. 3-12 has compiled some research [16] conducted by G. Proulx where he studied three Canadian government office buildings and determined an average evacuation time of 50 seconds. The office buildings received no warning of the egress test; however, the occupants were relatively prepared due to annual training conducted by the building owner. The buildings had an approximate occupant load of 1000 people. The building characteristics closely match those of the laboratory building: an occupant load is slightly less than 1000, emergency egress training conducted annually, and they are primarily office/lab space. Due to the similar nature of the Canadian office buildings to the laboratory building, a pre-movement time of 50 seconds will be assumed to complete the pre-evacuation tasks listed in section *8.10.5* of this report. The total evacuation time for the building population to exit out of the 5 main exits is 183 seconds.

$$t_{esc} = 50\ s + 112\ s = 162\ s\ (2.7\ min)$$

Keep in mind that this escape time does not reflect the Require Safe Egress Time (RSET). The RSET includes the detection time, t_d, and the notification time, t_n, which occur prior to pre-evacuation.

$$RSET = t_d + t_n + t_{esc}$$

8.11.1.4 *Scenario 1: Egress Analysis (Detection Time, t_d – Sprinkler Activation)*

The sprinklers are assumed to be ineffective for this fire scenario, however, we will still use a DETACT model to calculate a sprinkler activation time for comparison purposes.

Assume the computer workstation fire starts at the south region of the lobby. The fire starts on top of the desktop. The desktop is located 30 inches off the ground. The fire grows as a t-squared fire with a fire growth coefficient calculated as $\alpha = 0.0035\ kW/m^2$ in order to create a fire that grows to 300 kW in 300 seconds [17].

First Detector Response Time: The lobby is open to the corridor therefore the area is assumed to be infinite; however, the area is partially enclosed therefore the DETACT model will be used for calculating the sprinkler response time. A standard response sprinkler head is located 1.8 meters from the workstation. Per *NFPA 13, 3.6.1*, a standard response sprinkler head has a response time index (RTI) of $145\ (ft \cdot s)^{\frac{1}{2}}\ \left[80\ (m \cdot s)^{\frac{1}{2}}\right]$ or greater. This value contradicts the Plunge Test by FM (*FM 3210-2007*) *Table 4.6.1.1*.which states a $160\ °F$ rated detector must have an RTI less than $120\ (ft \cdot s)^{\frac{1}{2}}\ \left[68\ (m \cdot s)^{\frac{1}{2}}\right]$ in order to be considered a "standard response" detector. We will use the larger RTI to make a more conservative calculation:

$$r = 1.8\ m$$

The following assumptions will be used in our calculations:

$T_0 = 20\ °C$ (Ambient Temperature)
$T_d = 68.33\ °C = 155\ °F$ (Activation Temperature)

The ceiling height is 9.5 feet, but because the fire occurs on a 30 inch high desktop, the revised ceiling height is:

$$H = 9.5\ ft - \frac{30}{12}\ ft = 7\ ft = 2.1\ m$$

The r/h ratio is:

$$\frac{r}{H} = \frac{1.8\ m}{2.1\ m} = 0.857$$

The ratio of $\frac{r}{H} > 0.2$, therefore, we can assume the detector is located in the ceiling jet region as opposed to the plume region. Below is a table of parameters used to calculate the activation time of the detector:

Table 37 - DETACT Parameters (Scenario 1 – Sprinkler Activation)

INPUT PARAMETERS			CALCULATED PARAMETERS	
Ceiling Height (H)	2.1	m	r/H	0.857
Radial Distance (r)	1.8	m	dT(cj)/dT(pl)	0.332
Ambient Temperature (To)	20	C	du(cj)/du(pl)	0.227
Activation Temperature (Td)	68.33	C		
Response Time Index (RTI)	80	(m-s)1/2		
Fire Growth Power (n)	2	-		
Fire Growth Coefficient (α)	0.0035	kW/s^n		
Time Step	2	s		

The transient heat release rate was calculated using the t-squared growth model:

$$\dot{Q} = \alpha t^2$$

The change in plume temperature from ambient temperature as well as the plume velocity was calculated using the Alpert correlation for the plume region:

$$\Delta T_{g,pl} = 16.9 \frac{\dot{Q}^{2/3}}{H^{5/3}}$$

$$u_{g,pl} = \left(\frac{\dot{Q}}{H}\right)^{1/3}$$

The plume region values were used to calculate the ceiling jet values. The change in ceiling jet temperature from ambient temperature as well as the ceiling jet velocity was calculated using the Alpert correlation for the ceiling jet region:

$$\Delta T_{g,cj} = \Delta T_{g,pl} \frac{0.3}{(r/H)^{2/3}}$$

$$u_{g,cj} = u_{g,pl} \frac{0.2}{(r/H)^{5/6}}$$

The detector temperature was calculated by plugging the ceiling jet temperature and velocity into an Euler equation:

$$T_d^{(t+\Delta t)} = T_d^{(t)} + \frac{\sqrt{u_g^{(t)}}}{RTI}\left(T_g^{(t)} - T_d^{(t)}\right)\Delta t$$

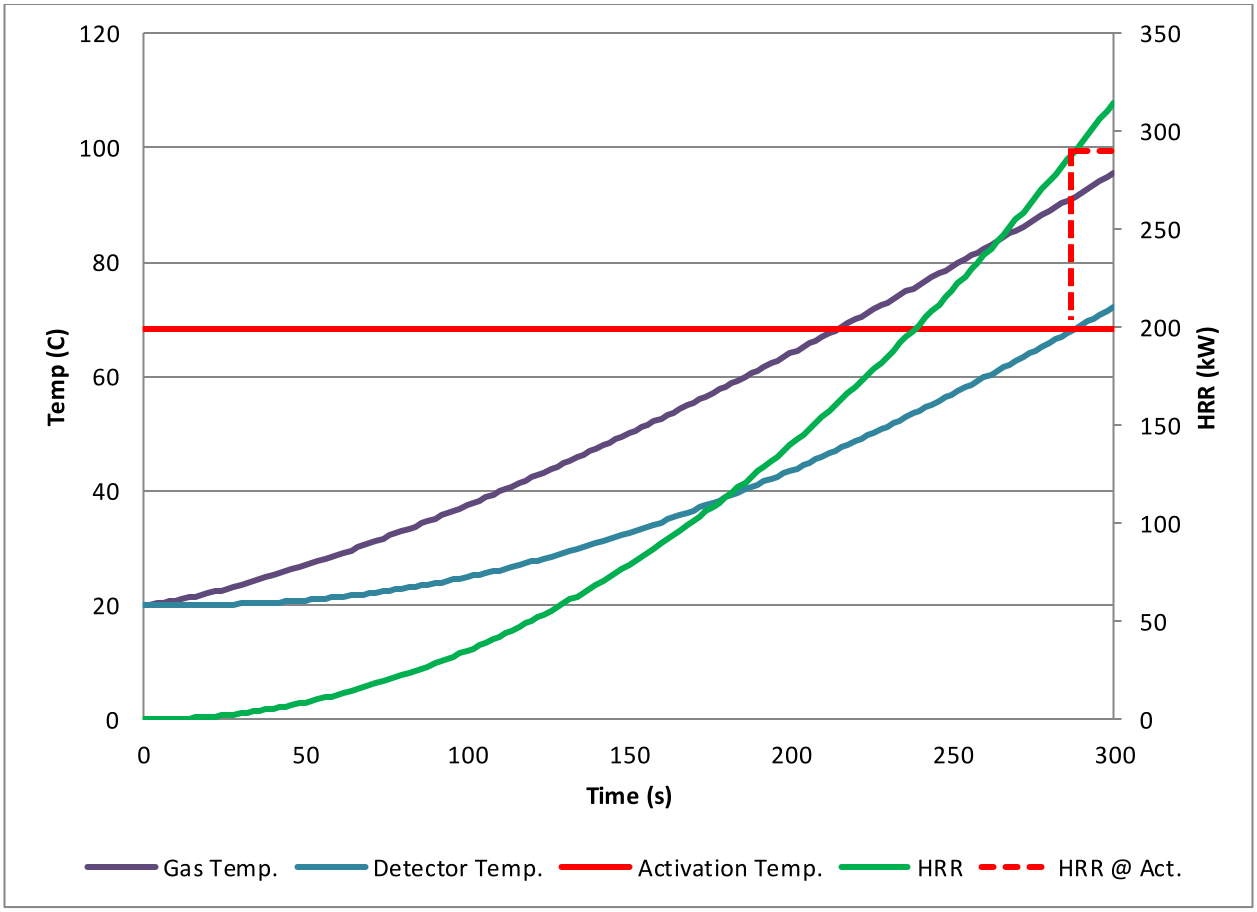

Figure 15 - DETACT Results (Scenario 1 – Sprinkler Activation)

Based on the graph above, the first sprinkler would activate 288 seconds after the fire began.

Heat Release Rate at First Detector Response: Based on the graph above, the heat release rate at the time of activation is 290 kW.

Uncertainty: The major uncertainty pertaining to this calculation is due the openness of the lobby to the corridor. The ceiling jet may take longer to reach the activation temperature because heat is lost to the corridor. The other uncertainty is related to the various reported RTI values from NFPA 13 and FM 3210.

8.11.1.5 *Scenario 1: Egress Analysis (Detection Time, t_d – Detector Activation)*

The following DETACT model is based on a smoke detector activation. The DETACT model requires an activation temperature input. Activation temperatures are difficult to calculate for a photovoltaic smoke detector because they activate based on smoke obscuration and not temperature. In NFPA 72 HB Table B.4.7.5.3, Schifiliti and Pucci combined data from Heskestad and Delichatsios to produce a table that approximates ceiling temperatures rise for smoke detector activation based on the fuel type. We are primarily dealing with plastic electronic cases and a polyurethane chair, therefore, we will assume a scattering temperature rise of $7.2\ °C$. Assuming the ambient temperature is $20\ °C$, the smoke detector will activate at a temperature of $27.2\ °C$. The RTI was set

to 1 due to the negligible lag time for a smoke detector. The following table and figure show the DETACT model parameters and results for smoke detector activation:

Table 38 - DETACT Parameters (Scenario 1 – Smoke Detector Activation)

INPUT PARAMETERS			CALCULATED PARAMETERS	
Ceiling Height (H)	2.1	m	r/H	0.857
Radial Distance (r)	1.8	m	dT(cj)/dT(pl)	0.332
Ambient Temperature (To)	20	C	du(cj)/du(pl)	0.227
Activation Temperature (Td)	27.2	C		
Response Time Index (RTI)	1	(m-s)1/2		
Fire Growth Power (n)	2	-		
Fire Growth Coefficient (α)	0.0035	kW/s^n		
Time Step	2	s		

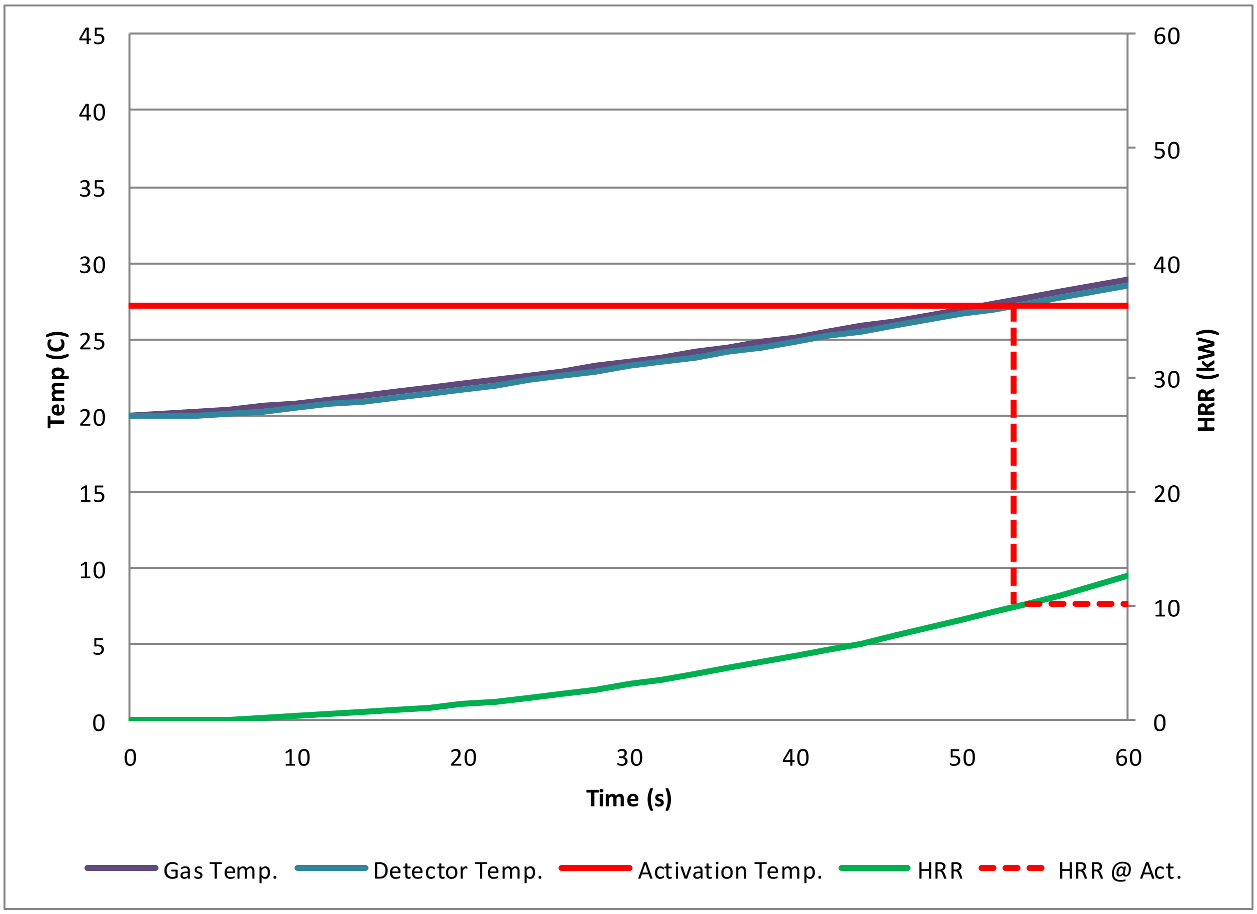

Figure 16 - DETACT Results (Scenario 1 – Smoke Detector Activation)

The smoke detector activates in 54 seconds. The HRR at the time of activation is 10.2 kW.

8.11.1.6 *Scenario 1: Egress Analysis (Uses and Limitations)*

Performing hand calculations to estimate egress time requires assumptions that unrealistically optimize the facility. In reality queuing would not instantly form and the building exits would not serve equal numbers of occupants during egress. Since instant queuing is assumed, the actual time to move from one's workstation to the door is also lost. The total evacuation time calculated from this method should be considered a decent measurement prior to performing computer evacuation models. The hand calculation may not be the best when it stands alone, but it can be very powerful when combined with a computer egress model for the purpose of validation.

8.11.1.7 *Scenario 1: Egress Analysis (Pathfinder)*

A computer model of the egress was replicated using Thunderhead Engineering's agent based evacuation simulation program called Pathfinder. Snapshots from the Pathfinder model of the laboratory building's evacuation can be found in Appendix E.

8.11.1.8 *Scenario 1: Egress Analysis (Pathfinder – Assumptions)*

- The building is at maximum occupancy
- The rooms don't have furniture or equipment

8.11.1.9 *Scenario 1: Egress Analysis (Pathfinder – Calculations)*

A total evacuation in Pathfinder took 106.3 seconds. The following figures show a summary of the simulation criteria and a graph of the remaining occupants versus time.

```
***SUMMARY***SUMMARY***SUMMARY***SUMMARY***SUMMARY***

Simulation:           518 Pathfinder
Mode:                 Steering
Total Occupants:      978
Last Out:             106.0s

[Components] All:     585
[Components] Doors:   334
Triangles:            3734
Startup Time:         0.1s
CPU Time:             21.1s
```

Figure 17 - Pathfinder Results Summary

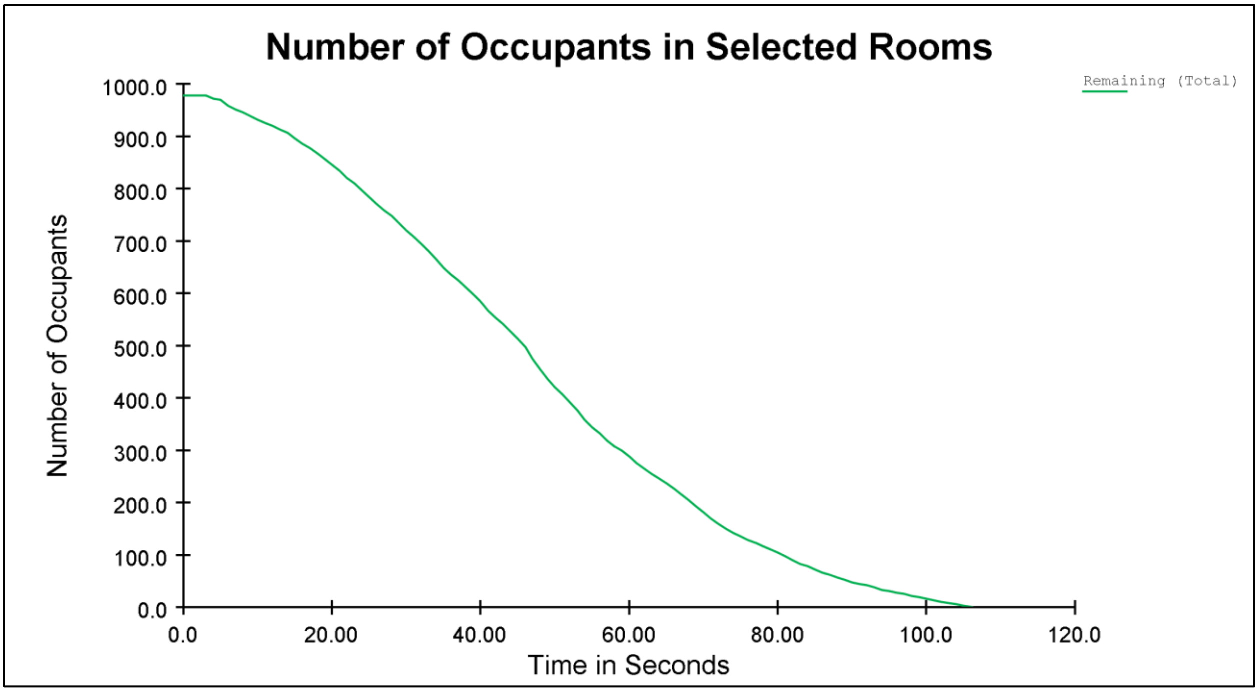

Figure 18 - Pathfinder Graph of Occupants vs. Time (Scenario 1)

8.11.1.10 *Scenario 1: Egress Analysis (Pathfinder – Uses and Limitations)*

The computer model does not account for things like human behavior during an egress. Some of the occupants in the model were exiting out of private exits that they normally wouldn't. The model also wasn't optimizing exit out of spaces. Occupants in the model would head for the nearest exit out of a space, where queuing was occurring, even though there were other available exits out of the space.

8.11.1.11 *Scenario 1: Egress Analysis (Comparison to Hand Calculation)*

The hand calculations estimated 112 seconds for the evacuation, which is about 6 seconds longer than the computer model. The results are very similar to each other, but they were achieved in different ways. The major assumptions in the hand calculation were instant queuing and only the 5 main exits were used and none of the private exits were used. The restriction in the computer model is the lack of balance among exits. The computer model also accounts for movement from the occupant's desk to the exit door instead of assuming instant queuing at the exits.

8.11.1.12 *Scenario 1: Egress Analysis (RSET)*

If we assume the notification time is negligible, the RSET for the lobby scenario, with sprinklers and smoke detectors, is calculated as:

$$\boldsymbol{RSET}\ (\boldsymbol{Sprinkler}) = t_d + t_{esc} = 288\ s + 162\ s = \mathbf{450}\ \boldsymbol{s}\ (\mathbf{7.5}\ \boldsymbol{min})$$

$$\boldsymbol{RSET}\ (\boldsymbol{Smoke\ Detector}) = t_d + t_{esc} = 54\ s + 162\ s = \mathbf{216}\ \boldsymbol{s}\ (\mathbf{3.6}\ \boldsymbol{min})$$

$$\boldsymbol{RSET}\ (\boldsymbol{Instant\ Detection}) = t_d + t_{esc} = 0\ s + 162\ s = \mathbf{162}\ \boldsymbol{s}\ (\mathbf{2.7}\ \boldsymbol{min})$$

The RSET using sprinklers would normally apply to this scenario; however, we are assuming the water supply to the sprinklers has been closed, rendering the sprinklers ineffective. The fire is expected to reach a maximum HRR of 300 kW in 300 seconds. The first sprinkler takes 288 seconds to activate which occurs only 12 seconds before the fire reaches its max HRR. This illustrates that even if the sprinklers were functioning, they would do very little to prevent the fire growth. The RSET using smoke detectors would normally not apply to this scenario because there are no smoke detectors in the lobby. We are calculating the RSET using a smoke detector in order to draw comparisons to the sprinkler and also to offer recommendations at the end of the performance-based analysis. The RSET for the lobby scenario with inactive sprinklers is unknown because the detection time would be dependent upon an occupant noticing the fire and activating the manual pull station. If an occupant is currently utilizing the lobby area when a fire breaks out, the detection time can be as little as 10 seconds (the time required to run to the nearest pull station). If no occupants are in the lobby at the time of the fire, the detection time may be 5 minutes or greater depending on when the smoke reaches nearby office windows.

8.11.1.13 *Scenario 1: FDS Model*

The following is an image form Smokeview 4 minutes into the fire. The smoke has already blocked 2 exits from the building and is spreading down the major corridors.

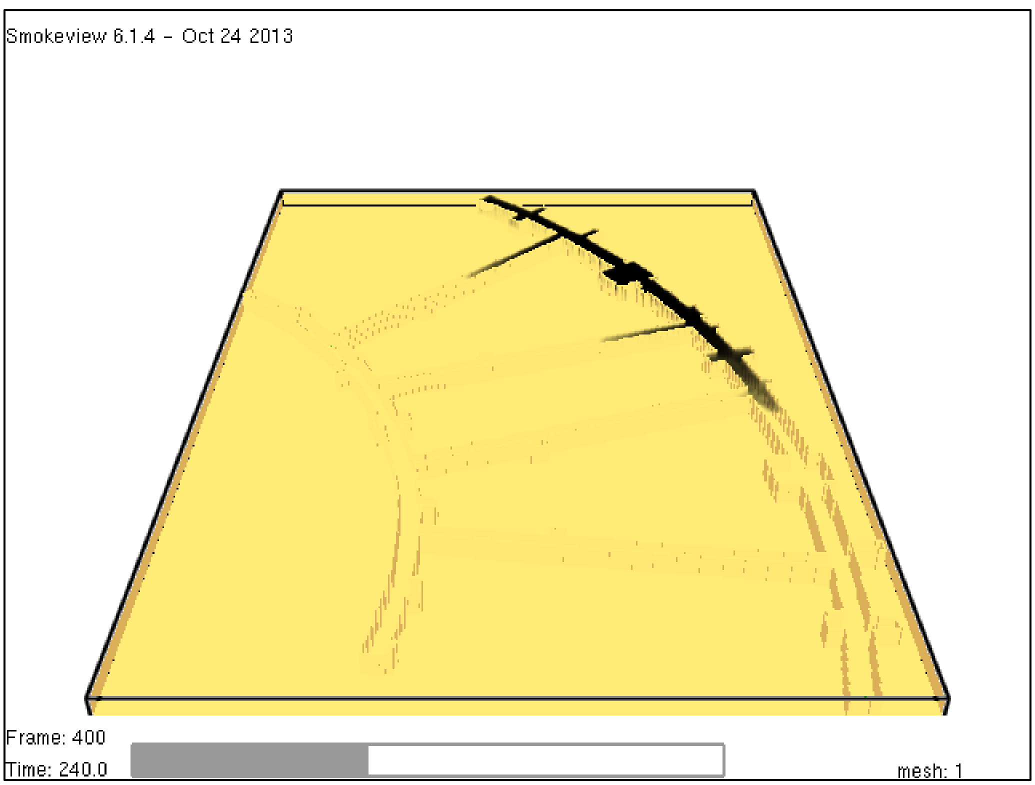

Figure 19 - Scenario 1 FDS

8.11.1.14 *Scenario 1: Results*

The following FDS results will show when tenability was exceeded for each criteria

Table 39 - Scenario 1 (FDS Results)

Criteria	Instant Detection	Smoke Detector	Sprinkler Activation	Reason
RSET (s)	**162**	**216**	**450**	
Flashover	Pass	Pass	Pass	Upper layer temperature of 500 C never exceeded
Temperature	Pass	Pass	Pass	A room temperature of 60 C was never exceeded below a height of 1.8 m
Visibility	Pass	200	200	Visibility drops below 13 m from the E door to the NE door, blocking 2 exits.
Smoke	Pass	Pass	220	The smoke layer descends below 6 feet at the E door in 220 s, eliminating the most common exit
CO	Pass	Pass	Pass	The CO concentration never exceed 1000 ppm

The graphs and figures resulting from the FDS model can be found in *Appendix M: Scenario 1 FDS Results*.

8.11.1.15 *Scenario 1: Summary*

This scenario assumed the sprinkler system was ineffective; therefore, the detection time is dependent on manual activation. Three different RSET time were calculated for scenario 1. The first RSET of 162 seconds corresponds to a negligible detection time. The seconds RSET of 216 seconds corresponds to smoke detector activation. The last RSET of 450 seconds corresponds to sprinkler activation. The first criterion to fail is visibility at 200 seconds. The first RSET passed the visibility criteria by only 38 seconds leaving very little time for manual detection. Regardless of the sprinklers functioning or the installation of a smoke detector, the first scenario can only be successful if manual activation of a manual pull station occurs within 38 seconds of the fire starting.

8.11.1.16 *Scenario 1: Uncertainty*

The greatest uncertainty is the time to detection. In order to compensate for the uncertainty, multiple RSETs were calculated.

8.11.2 Design Fire Scenario 2: Office – Heater Fire

The second fire scenario involved an office space heater located under a desk. The office is made up of numerous cubicle offices, a conference room, a kitchen, and 12 hard offices.

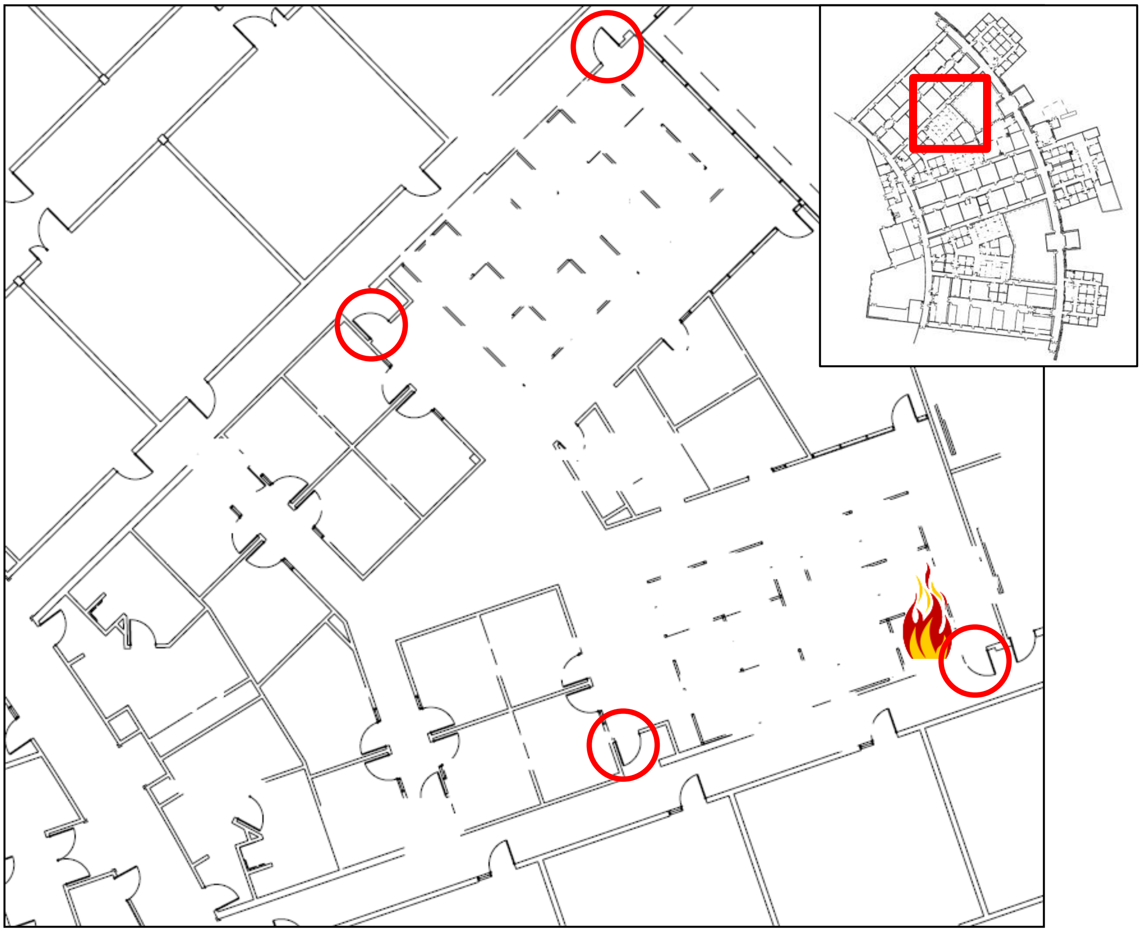

Figure 20 - Fire Scenario 2 (Location)

Space heaters are frequently used in office settings where not all occupants are comfortable with the pre-established office temperature. While an effort has been made to regulate space heater usage at Sandia, occasionally an unapproved (or a daisy-chained) heater is spotted under an occupant's desk. The fire will begin under the desk, initially shielded from sprinkler protection; therefore, a small space heater fire spreads to become a workstation fire before sprinkler activation can occur. In order to make a conservative calculation, it is assumed the workstation instantly catches fire at "$time = 0$". A shielded fire is the 5th required fire scenario from the LSC (LSC 5.5.3 (5)).

8.11.2.1 *Scenario 2: Heat Release Rates*

The HRR for a modern workstation was used from this scenario. The HRR curve was obtained from the SFPE HB Sect. 3-1:

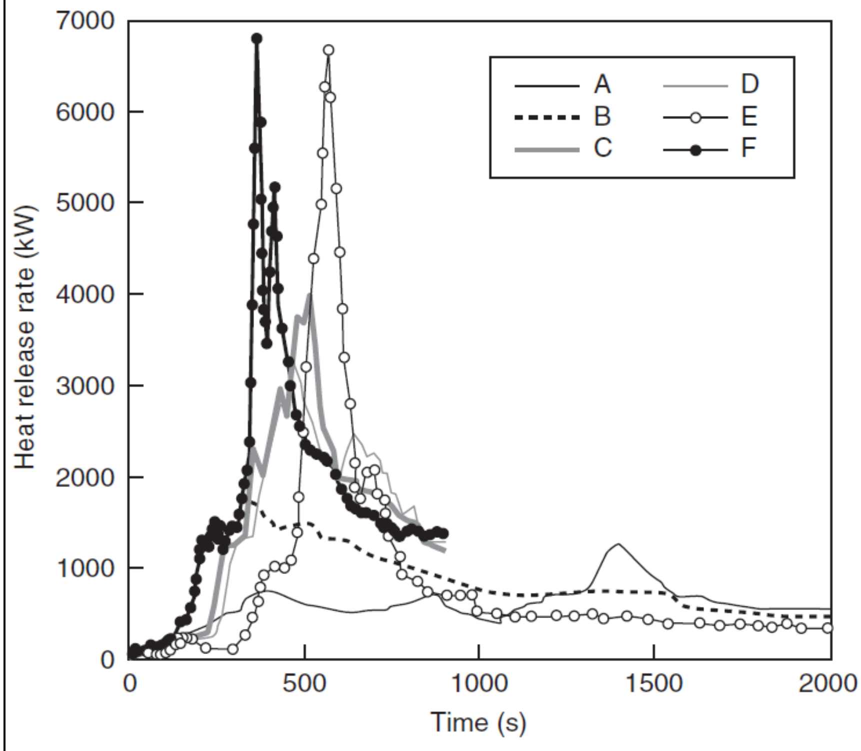

Figure 3-1.38. ***Office workstations.***

Figure 21 - HRR Workstation [18]

The first sprinkler activated in 140 seconds at a HRR of 510 kW. A sprinkler slightly closer to the fire would have activated around 129 seconds; however, the sprinkler has an intermediate-temperature rating of $200\ °F$ per NFPA 13 Table 8.3.2.5(a). The table requires all sprinklers heads within 2 feet 6 inches of a diffuser to have an intermediate-temperature rating. The FDS fire was modified to increase to 510 kW in 140 seconds. The FDS fire remained at 510 kW for the remainder of the model.

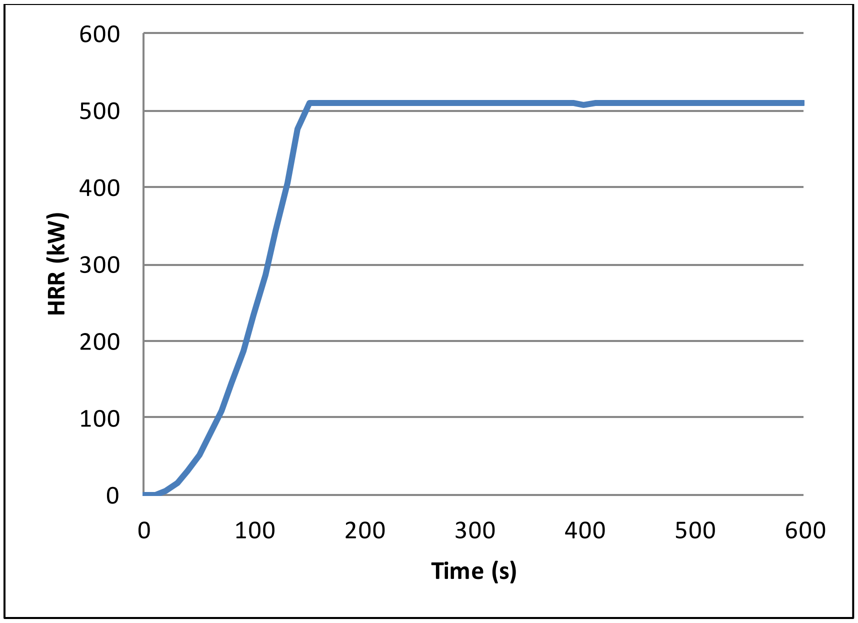

Figure 22 - HRR Workstation FDS

8.11.2.2 *Scenario 2: Egress Analysis (Evacuation Time, t_e – Pathfinder)*

A Pathfinder model was used to calculate the escape time for fire scenario 2. The pathfinder model didn't account for the fourth exit located in the south east corner of the room due its close proximity to the fire. The occupants in the office, where the fire occurs, will eventually exit the laboratory building, however, safe egress is assumed when they exit the office. The office doors are normally closed. The office doors will be open while the occupants exit the room, but they will automatically close after the last occupant exits. The smoke escaping from the room while the occupants exit will be minimal relative to the volume of the corridors; therefore it is assumed that all other occupants in the building will safely escape the building. The following figure shows the results from the Pathfinder model. The occupants exited the office in 28 seconds:

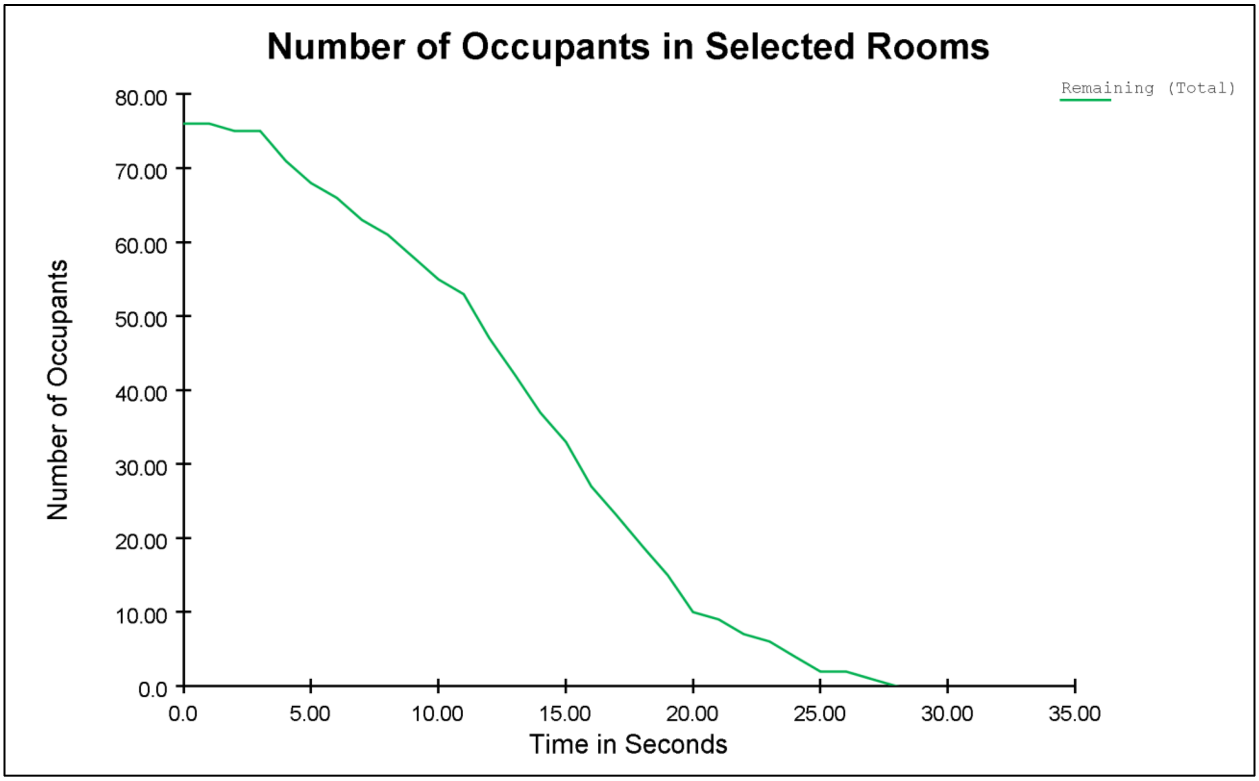

Figure 23 - Pathfinder Graph of Occupants vs. Time (Scenario 2)

8.11.2.3 *Scenario 2: Egress Analysis (Pre-Movement Time, t_{p-e})*

In this scenario all of the occupants in the office area are considered intimate with the fire because they are located in the same room as the fire. All of the pre-movement tests conducted by Proulx and other fire protection researchers identify pre-movement times for individuals who are not intimate with the fire. For this scenario, we will develop our own pre-movement time based on the Station Nightclub Fire Timetable [19] from the SFPE HB Table 3-12.1. The Station Nightclub Fire is relevant because most of the occupants were intimate with the fire. We will also utilize some pre-evacuation influencing factors reported by Shi in the journal article, "Developing a Database for Emergency Evacuation Model." [20]

Table 40 - Pre-Movement Time (Scenario 2)

Action	Time (s)
Reaction time (after noticing visible flame)	10
Notify others	10
TOTAL	**20**

Due to the intimacy of the fire, it is assumed the occupants will alert others by screaming while they exit the room. It is also assumed, upon seeing flames and

hearing screaming, the occupants will instantly stand up and escape without gathering belongings and shutting down their computers.

8.11.2.4 *Scenario 2: Egress Analysis (Detection Time, t_d – Sprinkler Activation)*

The sprinkler activation time was calculated using the FDS model. The first sprinkler activated in 140 seconds.

8.11.2.5 *Scenario 2: Egress Analysis (RSET)*

If all the occupants in the office (including the hard offices) alerted to the fire by their coworkers screaming, the detection time is negligible. The RSET is calculated as:

$$\boldsymbol{RSET}\ (\boldsymbol{Instant\ Detection}) = t_d + t_{p-e} + t_e = 0 + 20 + 28 = \mathbf{48}\ \boldsymbol{s}\ (\mathbf{0.8}\ \boldsymbol{min})$$

If the occupants located in the hard offices have their door closed and don't hear the screaming and commotion from their coworkers, the detection time will be 140 seconds (when sprinkler activation occurs):

$$\boldsymbol{RSET}\ (\boldsymbol{sprinkler}) = t_d + t_{p-e} + t_e = 140 + 20 + 28 = \mathbf{188}\ \boldsymbol{s}\ (\mathbf{3.1}\ \boldsymbol{min})$$

The two RSETs above are situational. If the hard office doors are open while occupied, the first RSET with instant detection will apply. If the hard office doors are normally closed and the occupant is currently listening to music, the seconds RSET with sprinkler activation will apply. Both RSETs will be compared in the results section for scenario 2.

8.11.2.6 *Scenario 2: FDS Model*

The following image is a rendering taken from Smokeview moments after the fire begins:

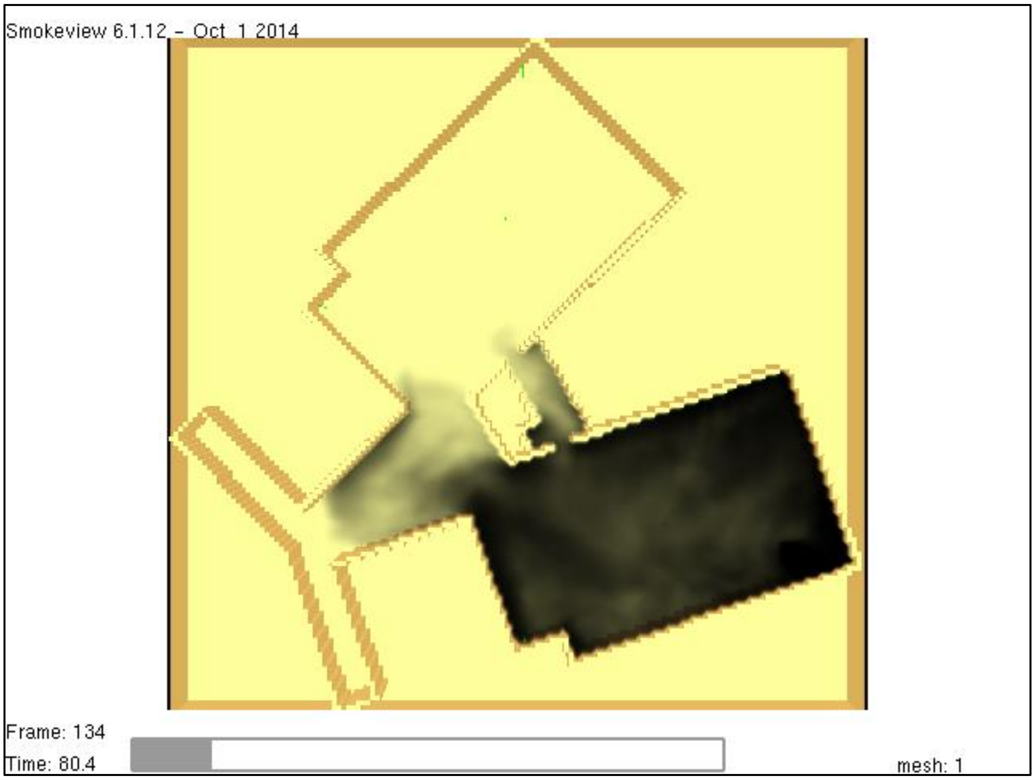

Figure 24 - Scenario 2 FDS

8.11.2.7 *Scenario 2: Results*

The following table compiles the FDS results to determine when tenability was exceeded for each criterion

Table 41 - Scenario 2 (FDS Results)

Criteria	**Instant Detection**	**Sprinkler Activation**	**Reason**
RSET (s)	**48**	**188**	
Flashover	Pass	Pass	Upper layer temperature of 500 C never exceeded
Temperature	Pass	165	A room temperature of 60 C was exceeded below a height of 1.8 m.
Visibility	Pass	80	Visibility drops below 13 m in the south office.
Smoke	Pass	100	The smoke layer descends below 6 feet in the south office.
CO	Pass	Pass	The CO concentration never exceed 1000 ppm

The graphs and figures resulting from the FDS model can be found in *Appendix N: Scenario 2 FDS Results*.

8.11.2.8 *Scenario 2: Summary*

Two different RSETs were calculated for Scenario 2. The first RSET of 48 seconds corresponded to all occupants being alerted to the fire by the screams from their coworkers. The model was successful using the first RSET. The second RSET of 188 corresponded to the occupants in the hard office not being alerted to the fire until the sprinkler activated. The model was unsuccessful using the second RSET.

8.11.3 Design Fire Scenario 3 – High Hazard Occupancy Fire

The last fire scenario will occur in a high hazard occupancy, and it will involve a spill fire containing 5 gallons of acetone. The amount and location of do not indicate the exact quantities and locations of chemicals in the laboratory building; however, the fire scenario is a good indication of possible hazards that may occur in any high hazard occupancy resulting from a spill fire.

8.11.3.1 *Scenario 3: Heat Release Rates*

The HRR, the area of the spill, and the burn time will all be calculated using the equations found in SFPE HB Sect. 2-15. The volume of acetone in cubic meters is:

$$\forall = 5\ gal = 0.0189\ m^3$$

Spills involving 25 gallons or less are assumed [21] to have a spill depth of:

$$\delta = 0.0007\ m$$

The initial spill area is calculated by dividing the volume by the thickness:

$$A_s = \frac{\forall}{\delta} = \frac{0.0189\ m^3}{0.0007\ m} = 27\ m^2$$

Once the fuel is on fire, the spill expands to approximately 155 percent of the initial spill area. The maximum area of the fire is:

$$A = 1.55A_s = 1.55(27\ m^2) = 41.85\ m^2$$

The diameter of the maximum area is:

$$D = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4 \times 41.85\ m^2}{\pi}} = 7.3\ m$$

The mass burning rate per unit area found in SFPE HB Table 3-1.21 are for pools with diameters increasing to infinity. Normally, we would modify this value by finding the limiting burning rate based using SFPE HB 2-15 Eq. 22:

$$\dot{m}'' = \dot{m}''_\infty[1 - \exp(-k\beta D)]$$

However, the previous equation is used for pool fires and not for spill fires. It has been determined by numerous tests found in SPFE HB Sect. 2-15 that the spill mass burning rate is approximately one-fifth the maximum pool mass burning rate, therefore:

$$\dot{m}'' = \frac{\dot{m}''_\infty}{5} = \frac{0.041\ kg \cdot m^{-2} \cdot s^{-1}}{5} = 0.0082\ \frac{kg}{m^2 s}$$

If we assume complete combustion, the steady state burning rate can now be calculated using the equation from SFPE HB Sect. 2-15 Eq. 24:

$$\dot{q} = \Delta h_c \dot{m}'' A = \left(25.8\ \frac{MJ}{kg}\right)\left(0.0082\ \frac{kg}{m^2 s}\right)(41.85\ m^2) = 8853.8\ kW$$

In “An Introduction for Fire Dynamics” by Drysdale, the closed cup flashpoint for Acetone is reported as $-14°C$. If we assume the initial room temperature to be $20°C$, then the acetone spill fire will be gas phase-controlled. A gas phase-controlled spill fire indicates the fire growth time is negligible, therefore, we will we assume the steady state burning HRR occurs instantaneously. The total burn time of the fuel will be calculated using the volume of fuel, the expanded area of the spill, and the mass burning rate:

$$t_b = \frac{m_f}{\dot{m}'' A} = \frac{V\rho}{\dot{m}'' A} = \frac{(0.0189\ m^3)\left(791\frac{kg}{m^3}\right)}{\left(0.0082\frac{kg}{m^2 s}\right)(41.85\ m^2)} = 43.6\ s$$

The fire in the FDS model will ramp up to 8853.8 kW in 1 second, remain at that HRR for 43.6 seconds, and then ramp down to 0 in 1 second.

8.11.3.2 *Scenario 3: Egress Analysis (Evacuation Time, t_e - Pathfinder)*

A Pathfinder model was used to calculate the escape time for fire scenario 3. Safe egress is considered when an occupant passes through a horizontal exit. The laboratory doors are normally closed. The smoke escaping from the lab while the occupants exit will be minimal relative to the volume of the corridors; therefore it is assumed that all other occupants in the building will safely escape the building. The following figure shows the results from the Pathfinder model. The occupants exited the laboratory area in 14 seconds:

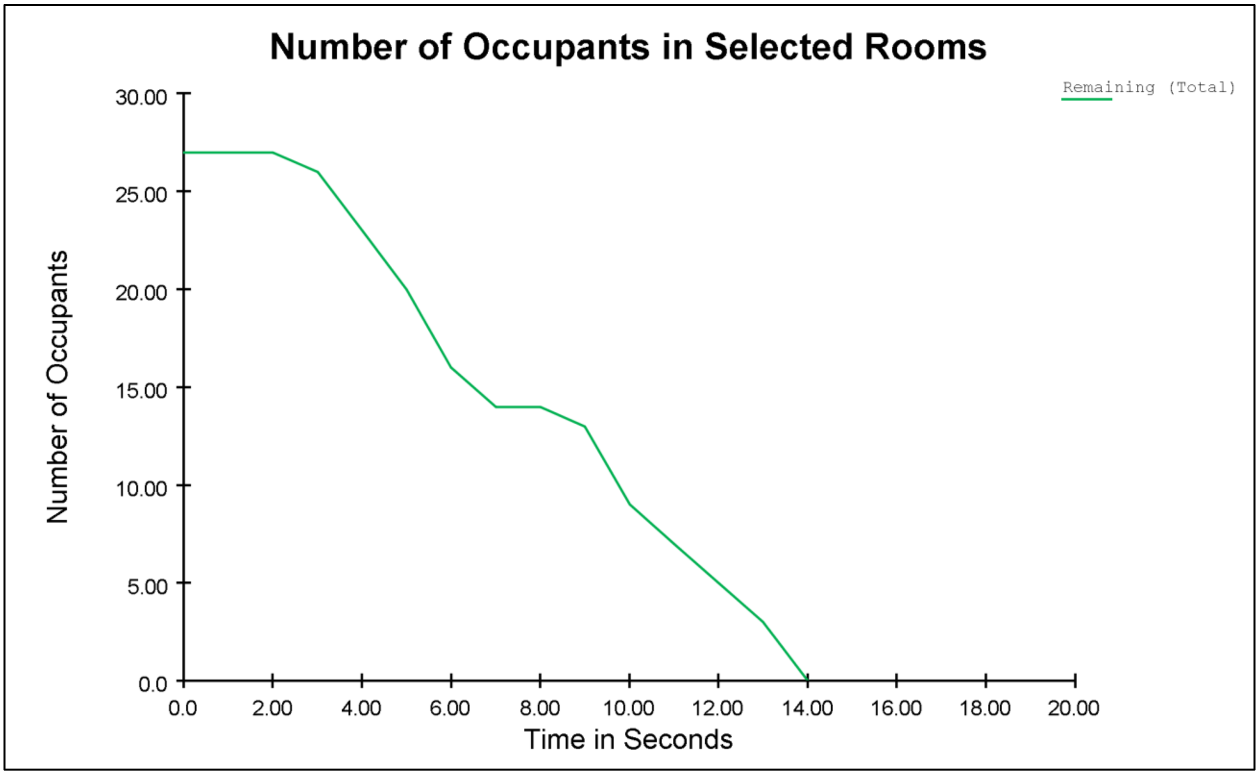

Figure 25 - Pathfinder Graph of Occupants vs. Time (Scenario 3)

8.11.3.3 *Scenario 3: Egress Analysis (Pre-Movement Time, t_{p-e})*

Not all of the occupants in the laboratory area are in the same room where the fire occurs; however, due to the nature of the high hazard occupancy, the occupants are trained to respond immediately to an alarm. The pre-movement time will be calculated similarly to scenario 2; however, we will reduce the reaction time to 3 seconds:

Table 42 - Pre-Movement Time (Scenario 3)

Action	Time (s)
Reaction time (after noticing visible flame)	3
Notify others	10
TOTAL	**13**

It is assumed the occupants will alert others by screaming while they exit the room. It is also assumed, upon seeing flames and hearing screams, the occupants will instantly stand up and escape without gathering belongings and shutting down their computers.

8.11.3.4 *Scenario 3: Egress Analysis (Detection Time, t_d)*

The high hazard occupancy is equipped with a High Sensitivity Smoke Detection (HSSD) system. The HSSD can detect a fire within its incipient phase by taking active air samples of the return air before it is diluted with makeup air. The area of the spill is

large and the fire reaches its max HRR in 1 second because it is gas phase controlled. We will assume the detection time is 3 seconds.

8.11.3.5 *Scenario 3: Egress Analysis (RSET)*

If we assume the notification time is negligible, the RSET for scenario 3 is calculated as:

$$\boldsymbol{RSET}\ (\boldsymbol{HSSD}) = t_d + t_{p-e} + t_e = 3 + 13 + 14 = \mathbf{30}\ \boldsymbol{s}\,(\mathbf{0.5}\ \boldsymbol{min})$$

8.11.3.6 *Scenario 3: FDS Model*

The following image is a rendering taken from Smokeview moments after the fire begins:

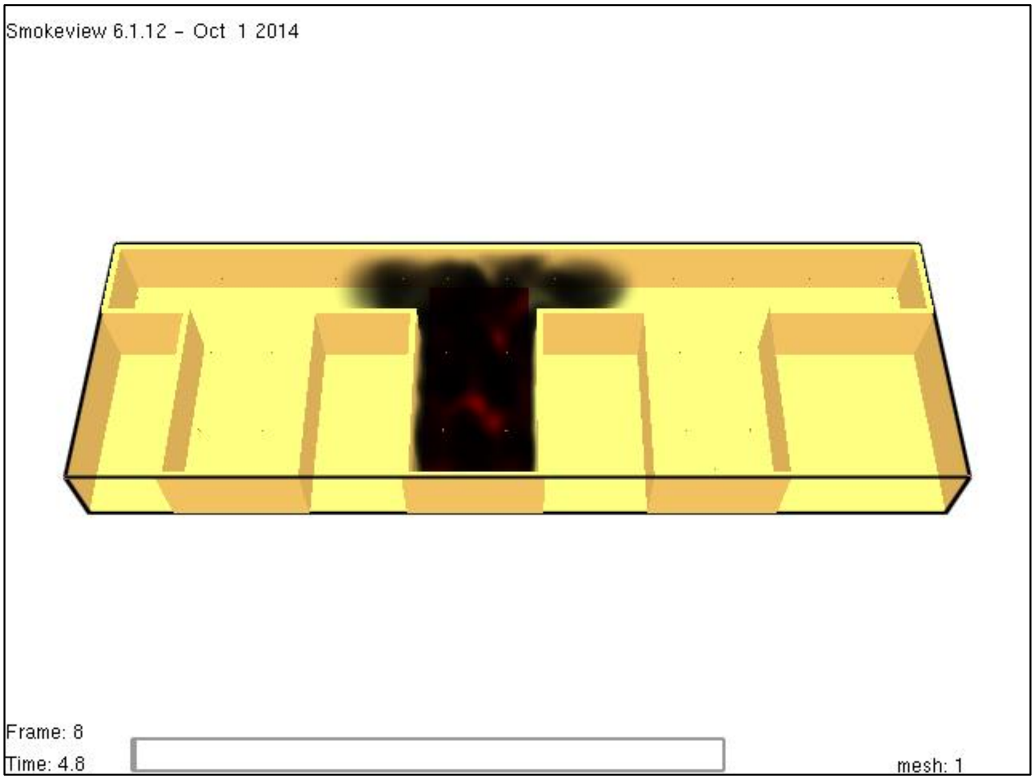

Figure 26 - Scenario 3 FDS

8.11.3.7 *Scenario 3: Results*

The following table compiles the FDS results to determine when tenability was exceeded for each criterion

Table 43 - Scenario 3 (FDS Results)

Criteria	Instant Detection	Reason
RSET (s)	**30**	
Flashover	Pass	Upper layer temperature of 500 C never exceeded
Temperature	14	A room temperature of 60 C was exceeded below a height of 1.8 m.
Visibility	14	Visibility drops below 13 m.
Smoke	14	The smoke layer descends below 6 feet.
CO	Pass	The CO concentration never exceed 1000 ppm

The graphs and figures resulting from the FDS model can be found in *Appendix O: Scenario 3 FDS Results*.

8.11.3.8 *Scenario 3: Summary*

Although the high hazard area is equipped with an HSSD and automatic sprinklers, the hazards of a gas-phase controlled spill fire quickly make the main room untenable. The fire reaches untenable condition in approximately 14 seconds, which is the same amount of time it takes occupants to evacuate the high hazard area (not including detection time and pre-evacuation time). The sprinklers took approximately 17 seconds to activate. The max HRR of the fire in not limited by the sprinklers because by the time sprinkler activation occurs, the fire has already reached its fuel limited max HRR. The major assumption made for scenario 3 is that the spill and ignition occur simultaneously. In reality, there may be enough time between the spill and ignition to allow the occupants to escape or clean up the spill. Scenario 3 was unsuccessful.

8.12 Risk Analysis

A qualitative risk analysis was performed following the FiRECAM risk model from SFPE HB Appendix 5-11.A. The qualitative risk analysis does not determine the probability of a fire occurrence; however, it provides a useful index tool where the risk of each scenario can be ranked and compared to each other. The results of the risk ranking can be used to determine which scenarios require a more in-depth qualitative analysis. The results will also be used to determine the priority level of the recommendations in the section 8.13.

8.12.1 Event Trees

An event tree was created for each of the three design fire scenarios. The probability of each step within the event trees were initially filled in with quantitative descriptions and then converted over to probability values for use in probability calculations. The

following table from SFPE HB Sect. 5-11 was used to convert quantitative descriptive to probability values:

Table 44 - Values Associated with Probability Desctiption

Quantitative Description	Associated Value
Very Low	0.05
Low	0.3
Moderate	0.5
High	0.7
Very High	0.95

The following table was used to assign a consequence level to each scenario. The table comes from SFPE HB Sect. 5-11. The consequence level considers both the property loss and the occupant impact.

Table 45 - Consequence Levels and Associated Loss Estimates

Quantitative Description	Property Loss ($1000)	Occupant Impact
Very Low	0-5	No deaths or injuries
Low	5-20	No deaths or injuries
Moderate	20-100	No deaths, minor injuries
High	100-1,000	No deaths, serious injuries
Very High	1,000-10,000	Small number of deaths and injuries
Extremely High	>10,000	Multiple deaths and injuries

Below are the event trees for the design fire scenarios. Each possible outcome is assigned a scenario ID for use in the risk ranking:

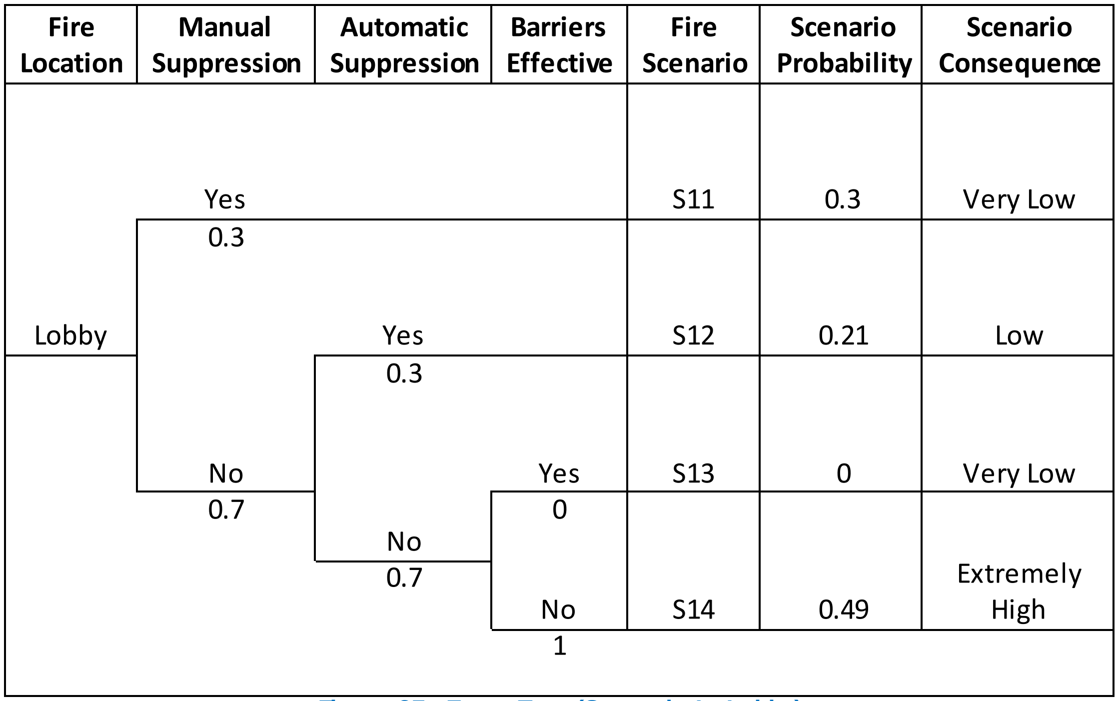

Figure 27 - Event Tree (Scenario 1 - Lobby)

Notice that the probability for barrier effectiveness is 0 because a barrier does not exist between the lobby and the corridor. Also, the probability of automatic suppression has been decreased from 0.95 to 0.3 because the sprinklers take too long to activate to be very effective.

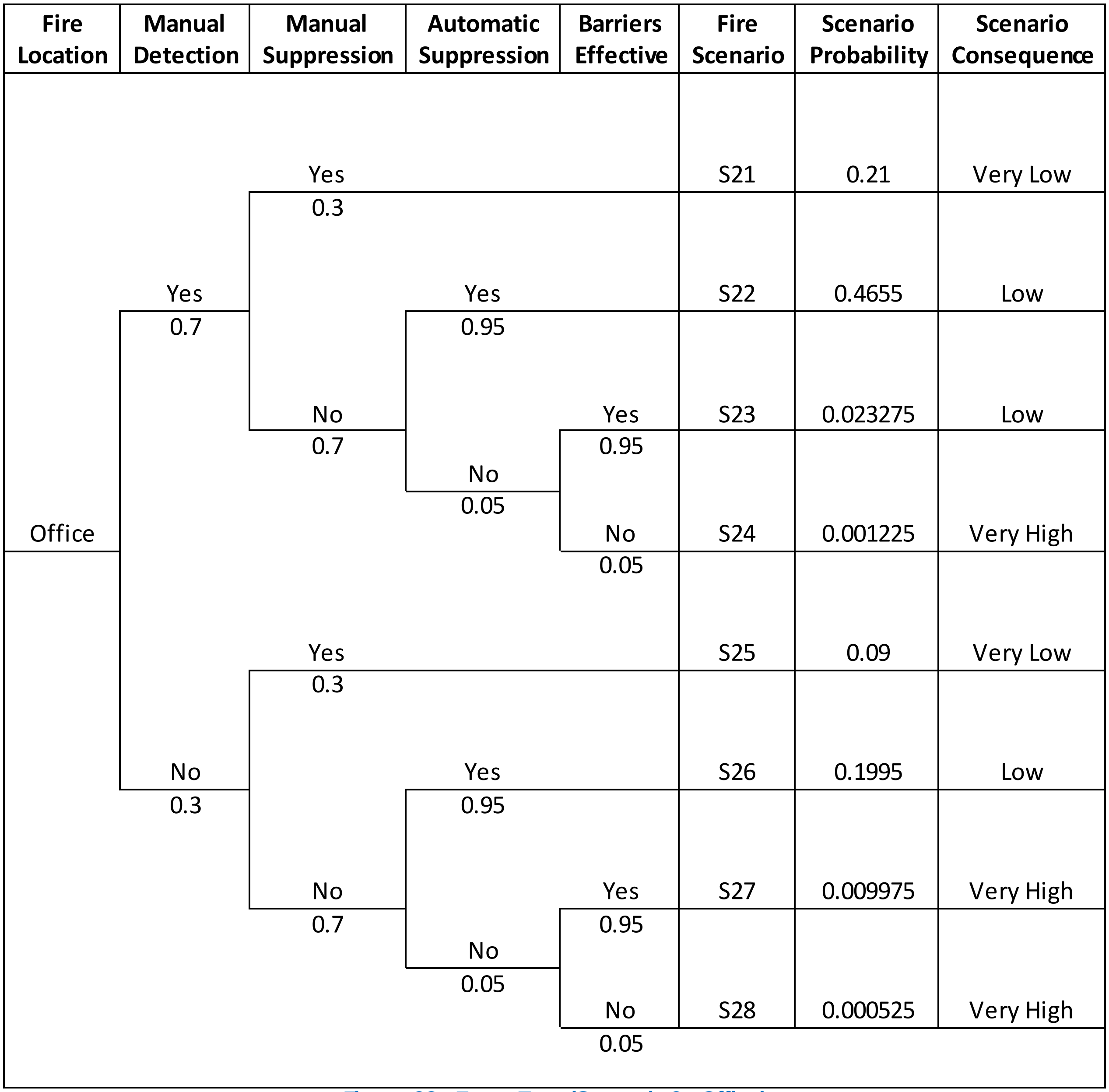

Figure 28 - Event Tree (Scenario 2 - Office)

Notice that a manual detection event has been added to the office design fire scenario. The manual detection event is supposed to represent whether the occupants in the hard offices are alerted to the fire by the screams of their coworkers.

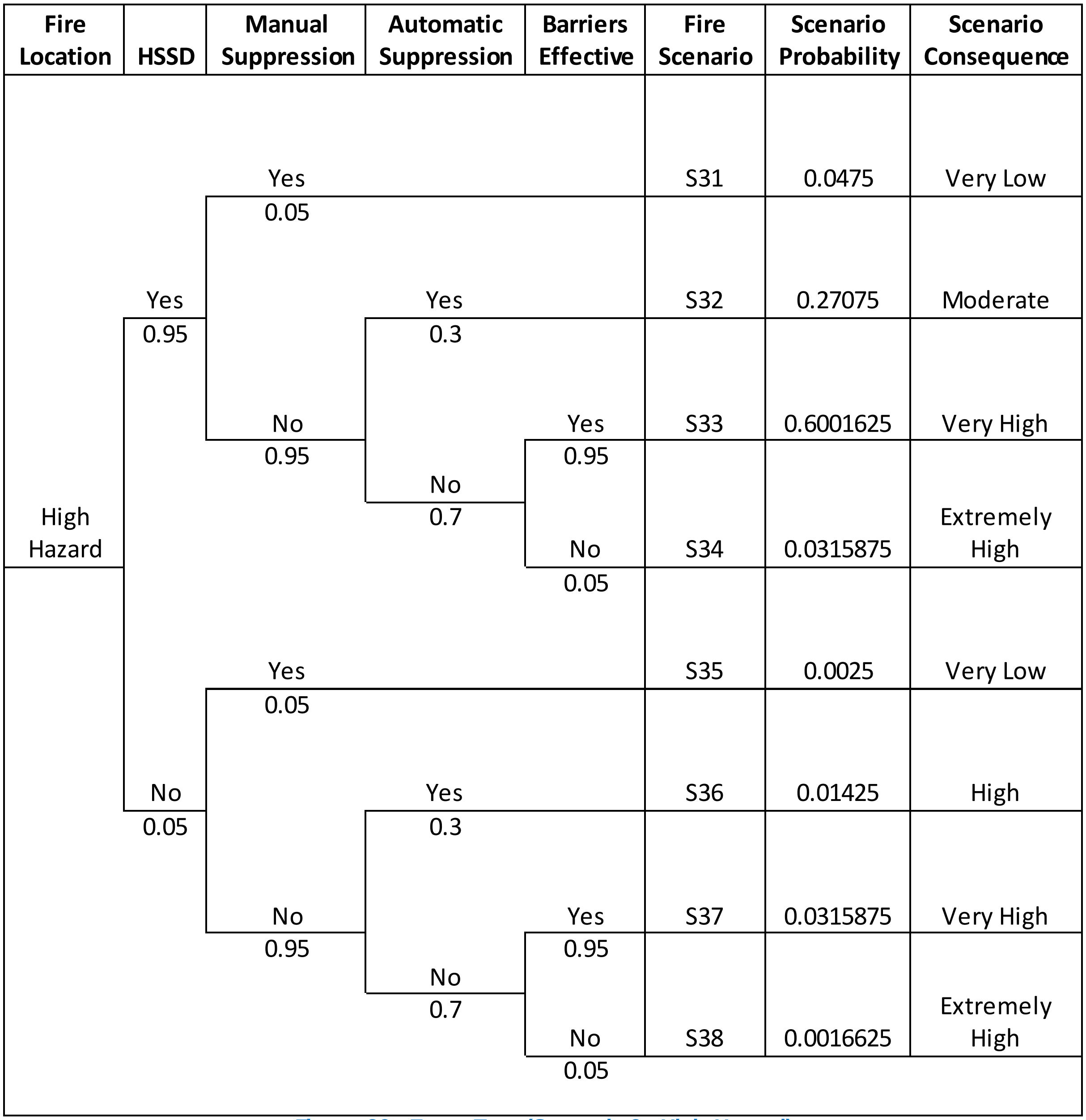

Figure 29 - Event Tree (Scenario 3 - High Hazard)

An HSSD event has been added to the scenario 3 event tree. The probability for manual and automatic suppression has been reduced due to the sudden overwhelming effects of a spill fire. The scenario's consequences are higher due to the value of the equipment in the high hazard area as well as the rapid fire growth leading to life loss.

8.12.2 Risk-Ranking Matrix

The following matrix plots each outcome according to its probability and consequence.

	Probability of Scenario Occurrence					
Consequence	Extremely Low (0.000-0.019)	Very Low (0.020-0.039)	Low (0.040-0.099)	Moderate (0.100-0.299)	High (0.300-0.499)	Very High (0.500-1.000)
Extremely High	S38	S34			S14	
Very High	S24, S28, S27	S37				S33
High	S36					
Moderate				S32		
Low		S23		S12, S26	S22	
Very Low	S13, S35		S25, S31	S21	S11	

Key

High Risk	Moderate Risk	Low Risk	Negligible Risk

Figure 30 - Risk-Ranking Matrix

The following table is a breakdown of the outcomes that pose a risk based on the risk ranking matrix. The table lists the highest risk scenarios in order starting from the top.

Table 46 - Description of most risk significant scenarios (descending order)

Scenario ID	Location	Description
S14	Lobby	Lobby fire is not manually detected. The fire is not suppressed by manual or automatic means. The fire spreads beyond the room of origin.
S33	High Hazard	Spill fire detected by HSSD. The fire is not suppressed by manual or automatic means. The fire is contained in the room of origin.
S34	High Hazard	Spill fire detected by HSSD. The fire is not suppressed by manual or automatic means. The fire spreads beyond the room of origin.
S38	High Hazard	Spill fire not detected by HSSD. The fire is not suppressed by manual or automatic means. The fire spreads beyond the room of origin.
S37	High Hazard	Spill fire not detected by HSSD. The fire is not suppressed by manual or automatic means. The fire is contained in the room of origin.
S32	High Hazard	Spill fire detected by HSSD. The fire is suppressed by automatic means.

8.13 Conclusion and Recommendations

The laboratory building passed all of the prescriptive-based design requirements except for the manual water supply calculation for the sprinkler system design. The laboratory building did not pass the performance-based design criteria. This section will offer prioritized recommendations to ensure maximum life safety while considering the cost to the owner for building modifications.

8.13.1 Recommendations

The following table lists the recommendations, based on the analysis, in a prioritized order:

Table 47 - Recommendations

Priority	Recommendation	Reason
1	Separate the two lobby areas from the corridor. Ensure the decorative wooden wall is enclosed or completely removed.	The smoke spread form the first scenario proved that a lobby fire would impact the entire population. The original recommendation was going to be the installation of a smoke detector to provide earlier detection than sprinkler activation; however, even with the installation of a smoke detector, the fire exceeded tenability limits before safe egress from the building. Separating the lobby from the corridor by means of a wall will prevent the smoke from spreading to the corridors and will also provide earlier sprinkler activation.
2	Reduce the probability of a chemical spill in the high hazard area. Reduce the potential spill area.	The third scenario proves that a 5 gallon spill of acetone and instant ignition would certainly lead to life-loss for those intimate with the fire. We can reduce the probability of a spill ever occurring by working with the building owner to ensure liquid chemicals are being stored, dispensed and transported appropriately. We will also work with the owner to determine if spill control, drainage, and containment is necessary where hazardous materials are used in order to reduce the area of a spill fire.
3	Install manual pull stations at the exits of the two office blocks located in the center of the building.	The second scenario proved to be fatal if the occupant in the hard offices were not quickly alerted to the fire. The manual pull stations will allow the fire alarm to be activated long before an automatic sprinkler activates.
4	Ensure proper ITM of all fire protection and life safety features.	Proper ITM will ensure the sprinkler water supply is always on. It will also ensure space heaters are being used appropriately and combustibles are not accumulating in the building.
5	Verify the discrepancy between the designer's sprinkler calculations and the hand calculations.	By performing a more thorough sprinkler analysis with a computer program such as AutoSPRINK,, we can determine if a water pump is necessary to provide enough water to meet the demand.

8.13.2 Conclusion

In general, a performance-based design must introduce fire hazards in order to assess the ability of the fire protection system to protect the occupants and the building from fire damage. Although the laboratory building doesn't pass the performance-based design, it does not imply a lack of safety to the occupants. A qualitative risk analysis would need to be performed in order to determine the actual probability of these fire scenarios occurring. The probability of the water supply being accidently turned off or a 5 gallon acetone spill is low. The results of this analysis should be used as a decision making tool to improve an already fire safe building.

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9.0 APPENDICES

9.1 Appendix A: Exits and Exit Signs

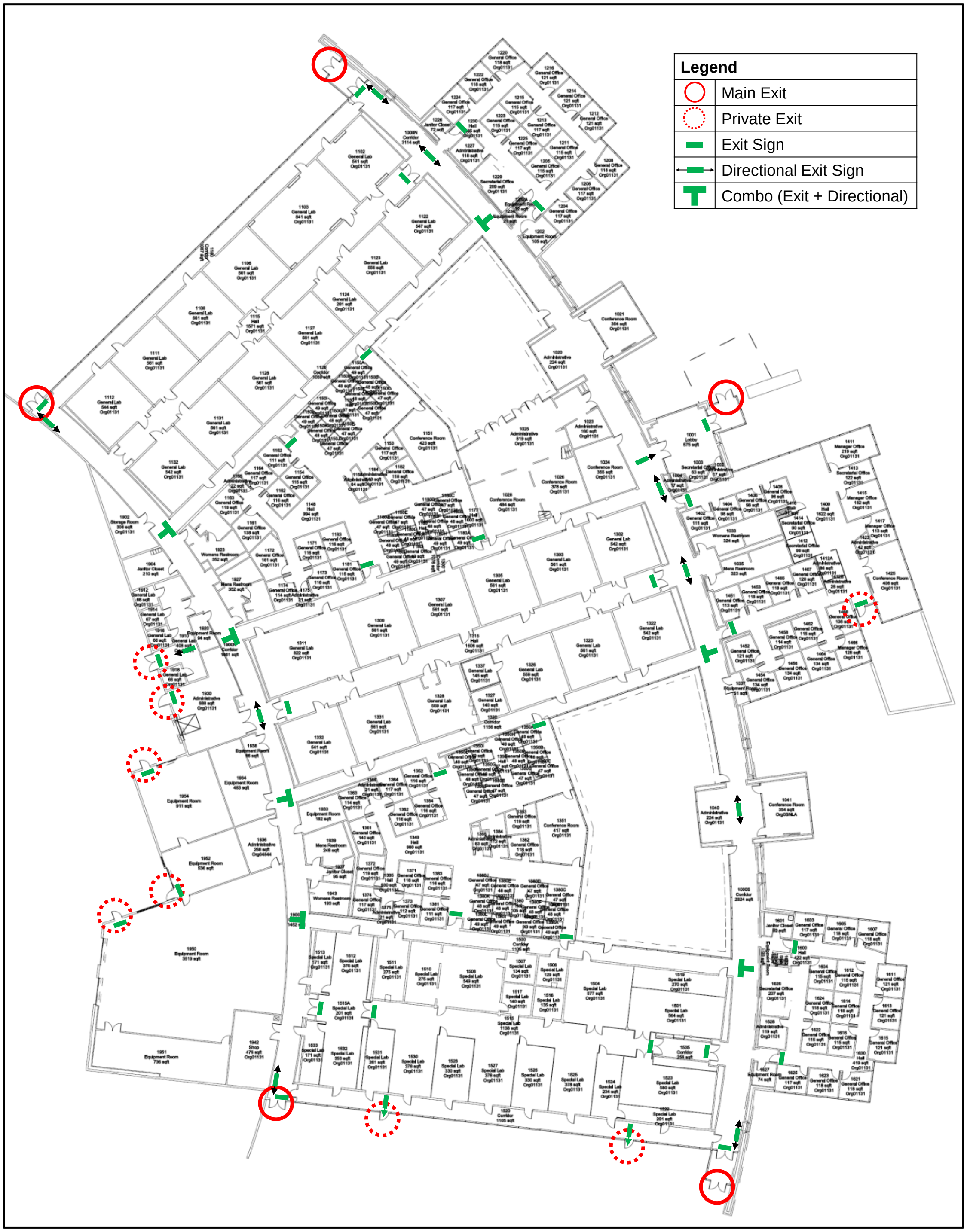


Figure 31 - Exits and Exit Signs

9.2 Appendix B: Occupant Loads

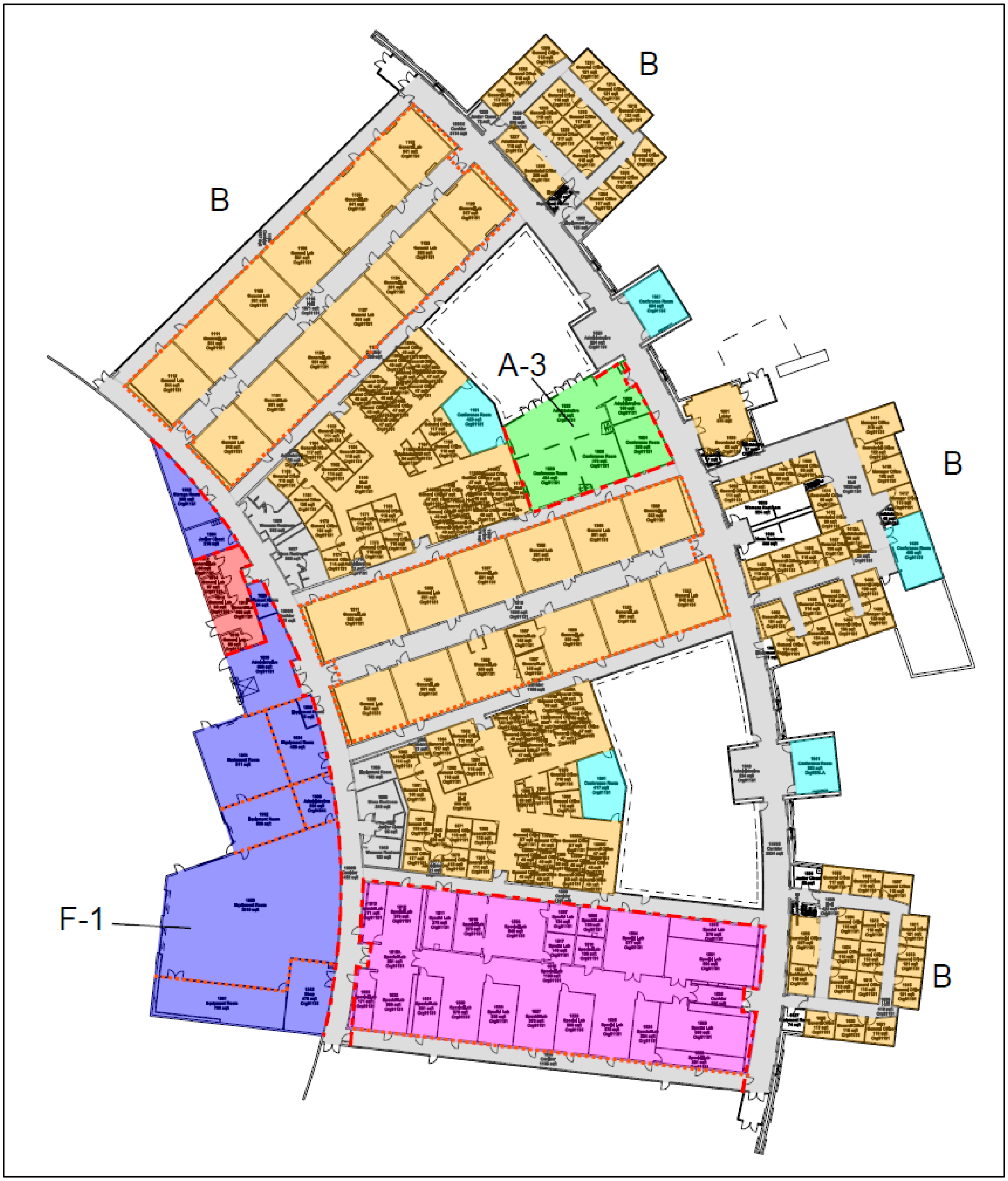


Figure 32 - Occupancy Classification IBC

Figure 32 is a layout of the laboratory building color coded for IBC occupancy classifications as well as corridors/aisles. The Building is divided into smaller sections for occupant load calculations.

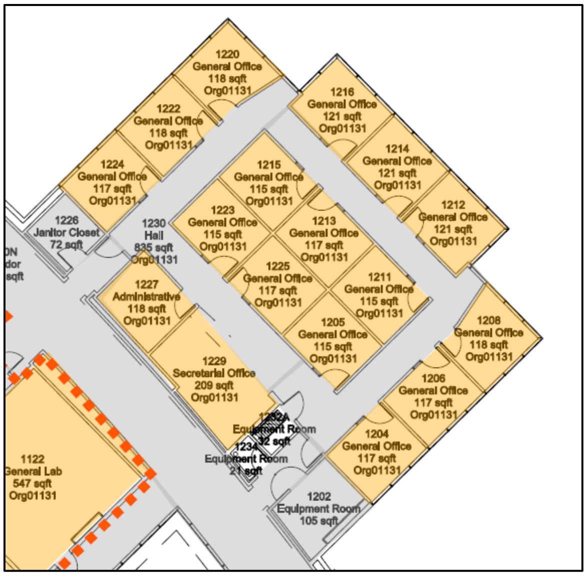


Figure 33 - OL Section 1

Table 48 - OL Section 1

Room	Use	Area (SF)	Factor	OL
1204	Business	117	100	1
1205	Business	115	100	1
1206	Business	117	100	1
1208	Business	118	100	1
1211	Business	115	100	1
1212	Business	121	100	1
1213	Business	117	100	1
1214	Business	121	100	1
1215	Business	115	100	1
1216	Business	121	100	1
1220	Business	118	100	1
1222	Business	118	100	1
1223	Business	115	100	1
1224	Business	117	100	1
1225	Business	117	100	1
1227	Business	118	100	1
1229	Business	209	100	2
TOTAL		**2089**		**18**

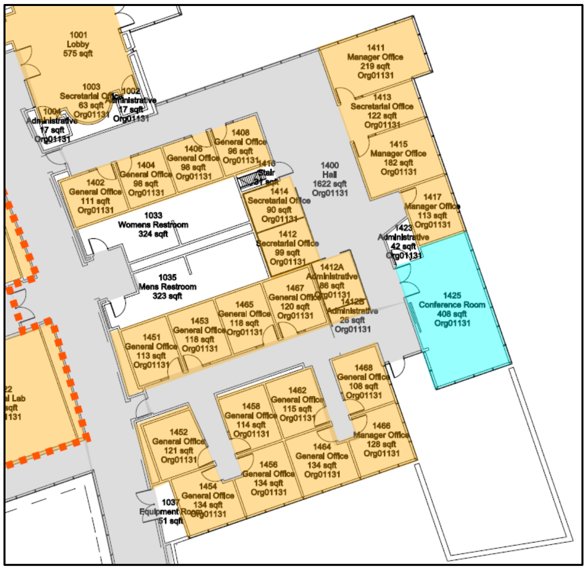


Figure 34 - OL Section 2

Table 49 - OL Section 2

Room	Use	Area (SF)	Factor	OL
1402	Business	111	100	1
1404	Business	98	100	0
1406	Business	98	100	0
1408	Business	96	100	0
1411	Business	219	100	2
1412	Business	99	100	0
1412A	Business	86	100	0
1412B	Business	26	100	0
1413	Business	122	100	1
1414	Business	90	100	0
1415	Business	182	100	1
1417	Business	113	100	1
1423	Business	42	100	0
1425	Assembly	408	15	27
1451	Business	113	100	1
1452	Business	121	100	1
1453	Business	118	100	1
1454	Business	134	100	1
1456	Business	134	100	1
1458	Business	114	100	1
1462	Business	115	100	1
1464	Business	134	100	1
1465	Business	118	100	1
1466	Business	128	100	1
1467	Business	120	100	1
1468	Business	108	100	1
TOTAL		**3247**		**45**

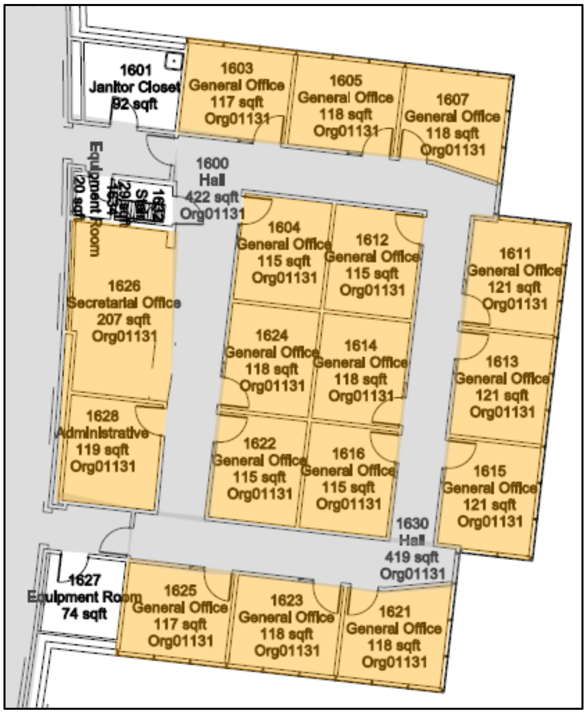


Figure 35 - OL Section 3

Table 50 - OL Section 3

Room	Use	Area (SF)	Factor	OL
1603	Business	117	100	1
1604	Business	115	100	1
1605	Business	118	100	1
1607	Business	118	100	1
1611	Business	121	100	1
1612	Business	115	100	1
1613	Business	121	100	1
1614	Business	118	100	1
1615	Business	121	100	1
1616	Business	115	100	1
1621	Business	118	100	1
1622	Business	115	100	1
1623	Business	118	100	1
1624	Business	118	100	1
1625	Business	117	100	1
1626	Business	207	100	2
1628	Business	119	100	1
TOTAL		**2091**		**18**

Figure 36 - OL Section 4

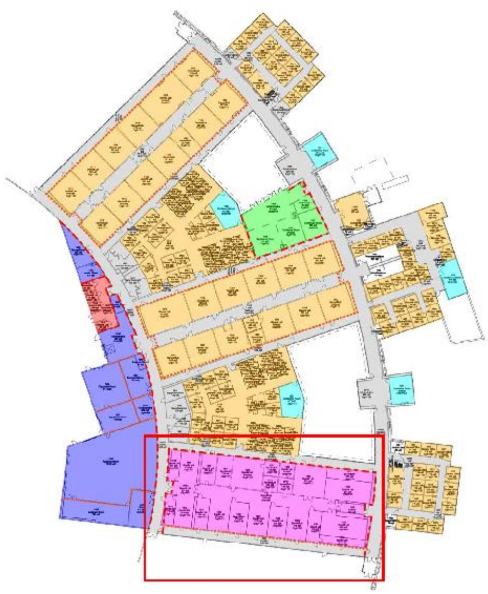


Table 51 - OL Section 4

Room	Use	Area (SF)	Factor	OL
1501	*	564	200	2
1504	*	577	200	2
1506	*	129	200	0
1507	*	134	200	0
1508	*	549	200	2
1510	*	275	200	1
1511	*	275	200	1
1512	*	376	200	1
1513	*	171	200	0
1515	*	1138	200	5
1515A	*	201	200	1
1516	*	135	200	0
1517	*	140	200	0
1519	*	270	200	1
1522	*	201	200	1
1523	*	580	200	2
1524	*	234	200	1
1525	*	378	200	1
1526	*	330	200	1
1527	*	378	200	1
1528	*	330	200	1
1530	*	378	200	1
1531	*	261	200	1
1532	*	353	200	1
1533	*	171	200	0
TOTAL		**8528**		**27**

*Intentionally left blank

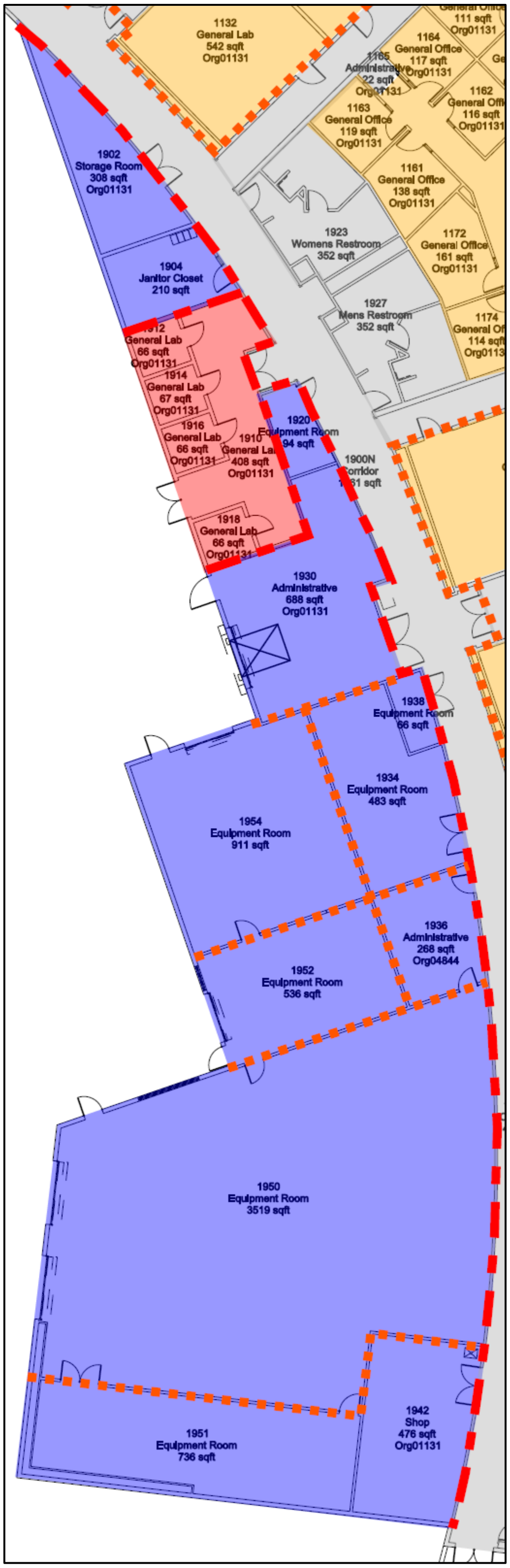
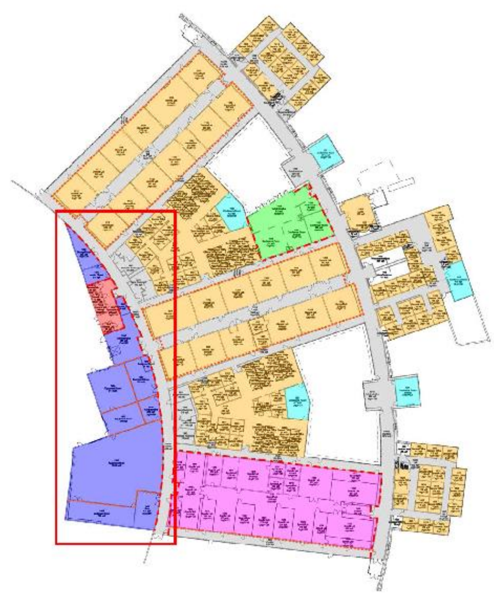


Figure 37 - OL Section 5

Table 52 - OL Section 5

Room	Use	Area (SF)	Factor	OL
1902	Storage	308	300	1
1904	Storage	210	300	0
1910	Storage	408	300	1
1912	Storage	66	300	0
1914	Storage	67	300	0
1916	Storage	66	300	0
1918	Storage	66	300	0
1920	Equip Rm.	94	300	0
1930	Business	688	100	6
1934	Equip Rm.	483	300	1
1936	Business	268	100	2
1938	Equip Rm.	66	300	0
1942	Business	476	100	4
1950	Equip Rm.	3519	300	11
1951	Equip Rm.	736	300	2
1952	Equip Rm.	536	300	1
1954	Equip Rm.	911	300	3
TOTAL		**8968**		**32**



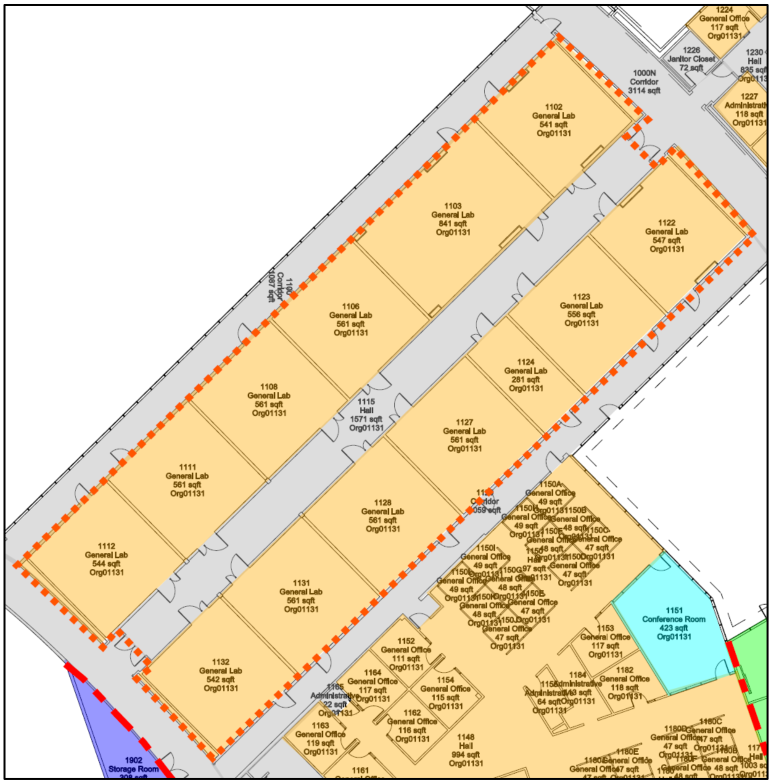


Figure 38 - OL Section 6

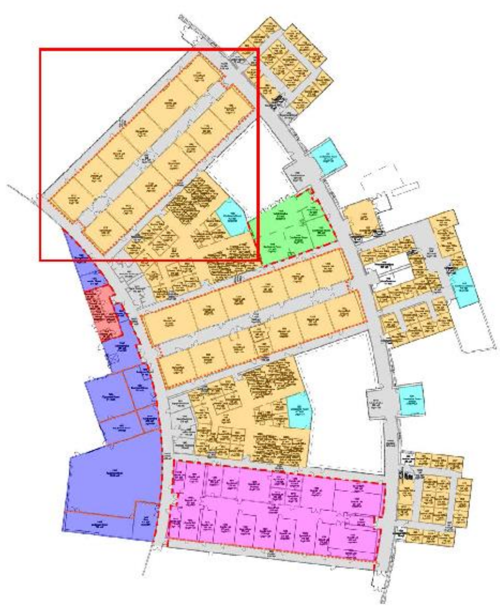


Table 53 - OL Section 6

Room	Use	Area (SF)	Factor	OL
1102	Business	541	100	5
1103	Business	841	100	8
1106	Business	561	100	5
1108	Business	561	100	5
1111	Business	561	100	5
1112	Business	544	100	5
1122	Business	547	100	5
1123	Business	556	100	5
1124	Business	281	100	2
1127	Business	561	100	5
1128	Business	561	100	5
1131	Business	561	100	5
1132	Business	542	100	5
TOTAL		**7218**		**65**

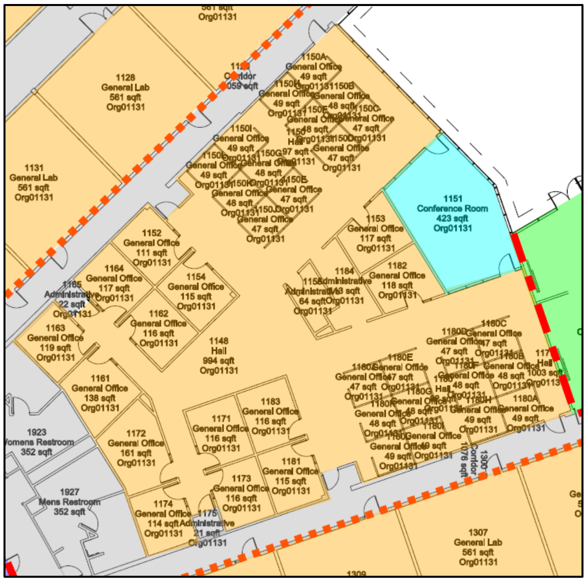


Figure 39 - OL Section 7

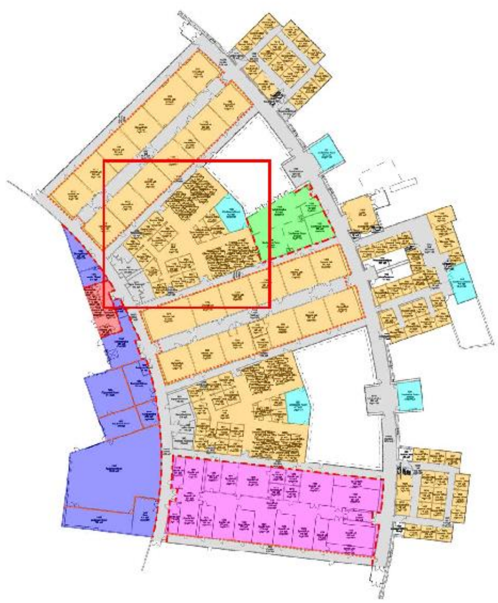


Table 54 - OL Section 7

Room	Use	Area (SF)	Factor	OL
1151	Assembly	423	15	28
1152	Business	111	100	1
1153	Business	117	100	1
1154	Business	115	100	1
1155	Storage	64	300	0
1161	Business	138	100	1
1162	Business	116	100	1
1163	Business	119	100	1
1164	Business	117	100	1
1165	Storage	22	300	0
1171	Business	116	100	1
1172	Business	161	100	1
1173	Business	116	100	1
1174	Business	114	100	1
1175	Storage	21	300	0
1181	Business	115	100	1
1182	Business	118	100	1
1183	Business	116	100	1
1184	Business	113	100	1
Cubicles*	Business	3343	100	33
TOTAL		**5675**		**76**

**The total area of section 7 is 5675 sq. ft. The area for the "Cubicles" section was calculated by subtracting the area of the hard offices and the conference room from the total of 5675 sq. ft.*

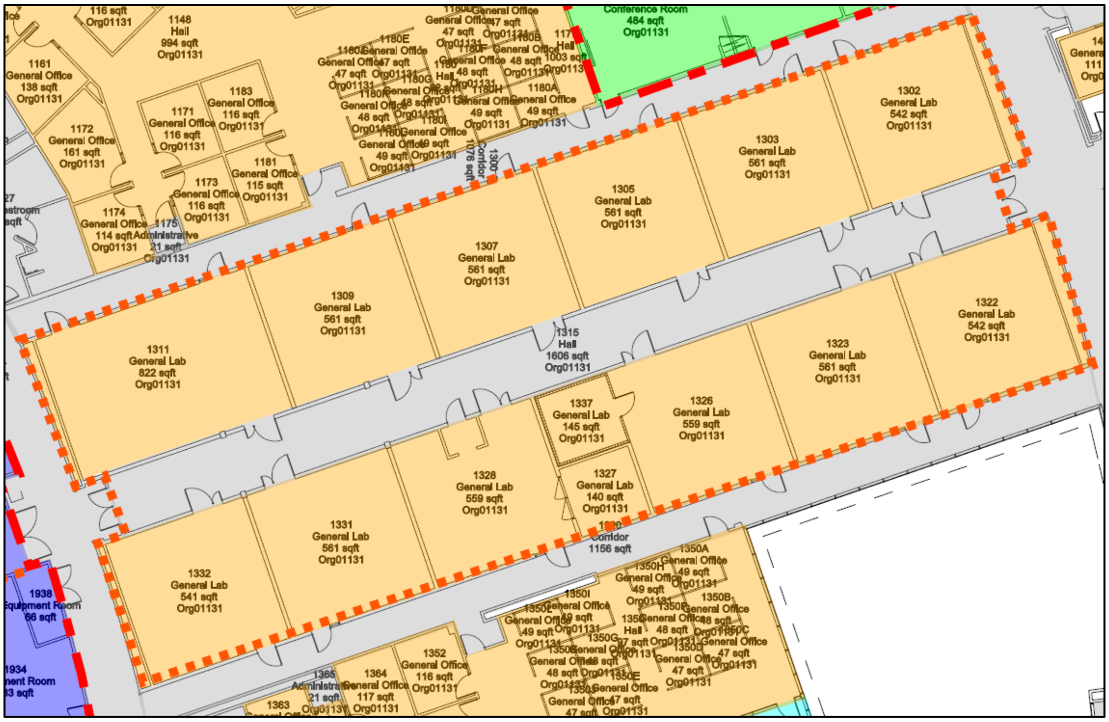


Figure 40 - OL Section 8

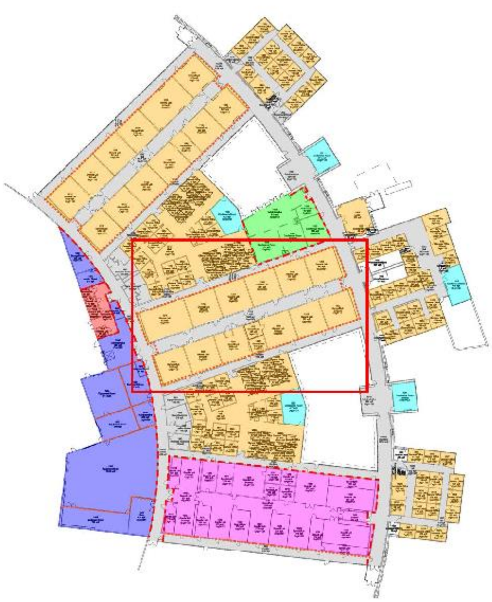


Table 55 - OL Section 8

Room	Use	Area (SF)	Factor	OL
1302	Business	542	100	5
1303	Business	561	100	5
1305	Business	561	100	5
1307	Business	561	100	5
1309	Business	561	100	5
1311	Business	822	100	8
1322	Business	542	100	5
1323	Business	561	100	5
1326	Business	559	100	5
1327	Business	140	100	1
1328	Business	559	100	5
1331	Business	561	100	5
1332	Business	541	100	5
1337	Business	145	100	1
TOTAL		**7216**		**65**

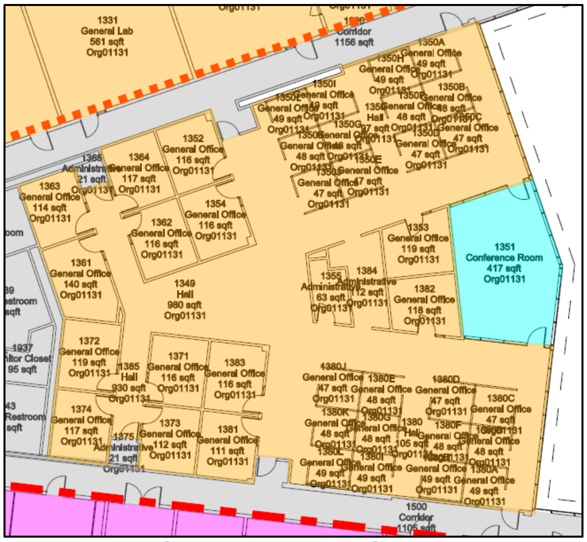


Figure 41 - OL Section 9

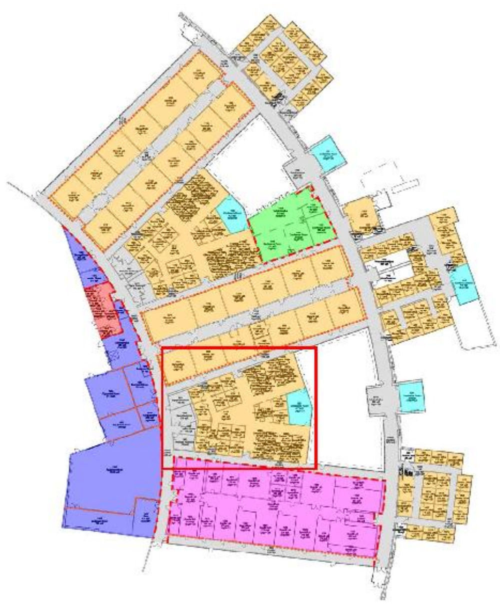


Table 56 - OL Section 9

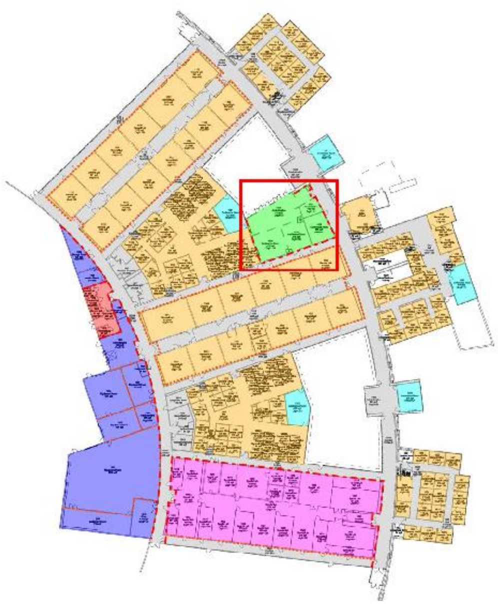
Room	Use	Area (SF)	Factor	OL
1351	Assembly	417	15	27
1352	Business	116	100	1
1353	Business	119	100	1
1354	Business	116	100	1
1355	Storage	63	300	0
1361	Business	140	100	1
1362	Business	116	100	1
1363	Business	114	100	1
1364	Business	117	100	1
1365	Storage	21	300	0
1371	Business	116	100	1
1372	Business	119	100	1
1373	Business	112	100	1
1374	Business	117	100	1
1375	Storage	21	300	0
1381	Business	111	100	1
1382	Business	118	100	1
1383	Business	116	100	1
1384	Business	112	100	1
Cubicles*	Business	3319	100	33
TOTAL		**5600**		**75**

**The total area of section 9 is 5600 sq. ft. The area for the "Cubicles" section was calculated by subtracting the area of the hard offices and the conference room from the total of 5600 sq. ft.*

Figure 42 - OL Section 10

Table 57 - OL Section 10

Room	Use	Area (SF)	Factor	OL
1023	Storage	160	300	0
1024	Assembly	355	15	23
1025	Assembly	819	15	54
1026	Assembly	378	15	25
1028	Assembly	484	15	32
TOTAL		**2196**		**134**



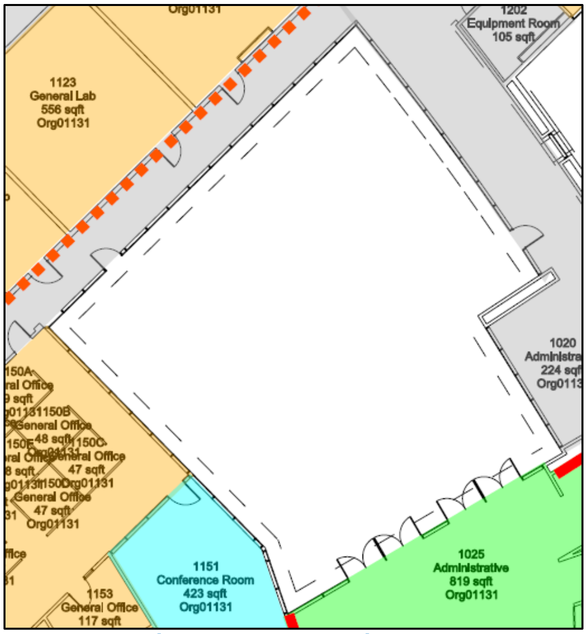
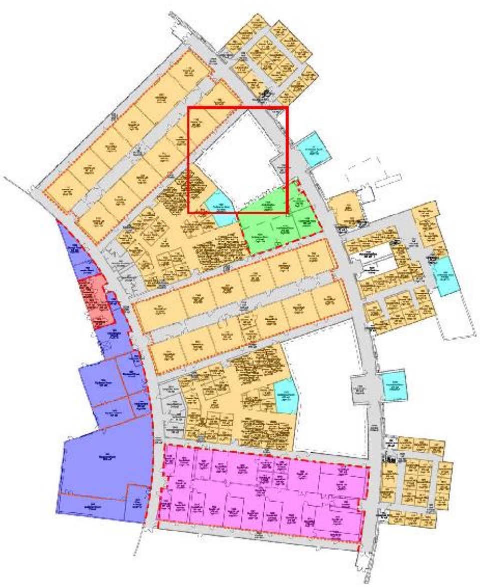


Figure 43 - OL Section 11

Table 58 - OL Section 11

Room	Use	Area (SF)	Factor	OL
North Court	Assembly	1868	15	124
TOTAL		**1868**		**124**



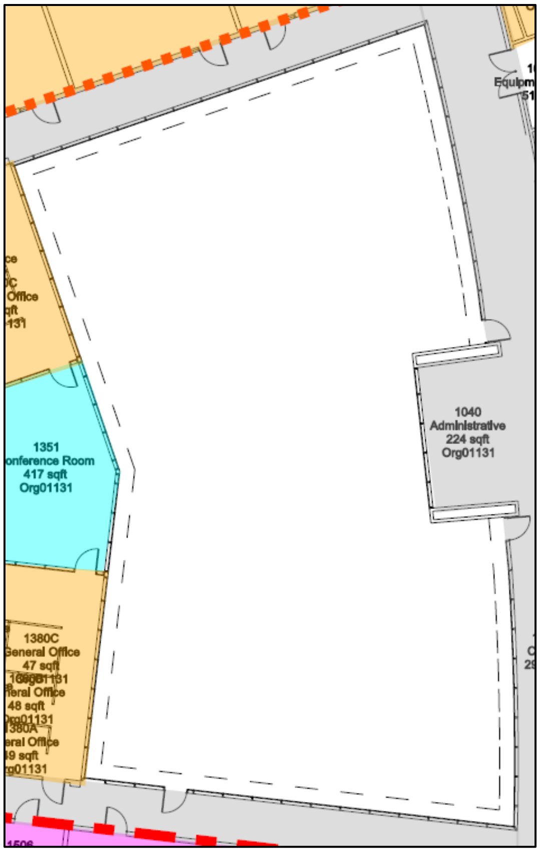


Figure 44 - OL Section 12

Table 59 - OL Section 12

Room	Use	Area (SF)	Factor	OL
South Court	Assembly	3200	15	213
TOTAL		**3200**		**213**

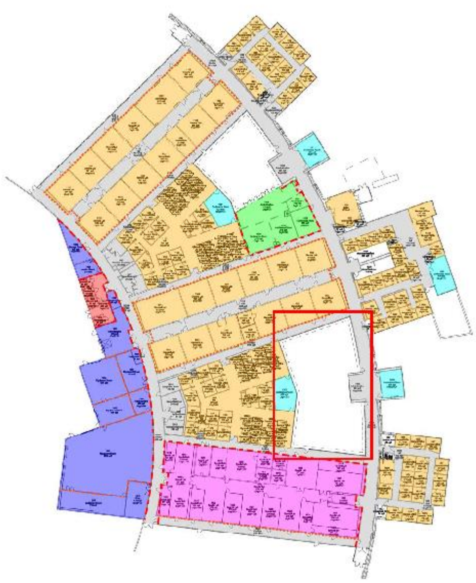


Figure 45 - OL Section 13

Table 60 - OL Section 13

Room	Use	Area (SF)	Factor	OL
1021	Assembly	354	15	23
1020	Waiting	224	15	14
1001	Business	638	100	6
1004	Storage	17	300	0
1002	Storage	17	300	0
1037	Storage	51	300	0
1040	Waiting	224	15	14
1041	Assembly	354	15	23
1601	Storage	92	300	0
1634	Equip Rm.	20	300	0
1627	Equip Rm.	74	300	0
1937	Storage	95	300	0
1933	Equip Rm.	182	300	0
1226	Storage	72	300	0
1202	Equip Rm.	105	300	0
1234	Equip Rm.	21	300	0
TOTAL		**2540**		**80**

**Section 13 consists of all other rooms that open directly to the main corridor.*

9.3 Appendix C: Travel Distance

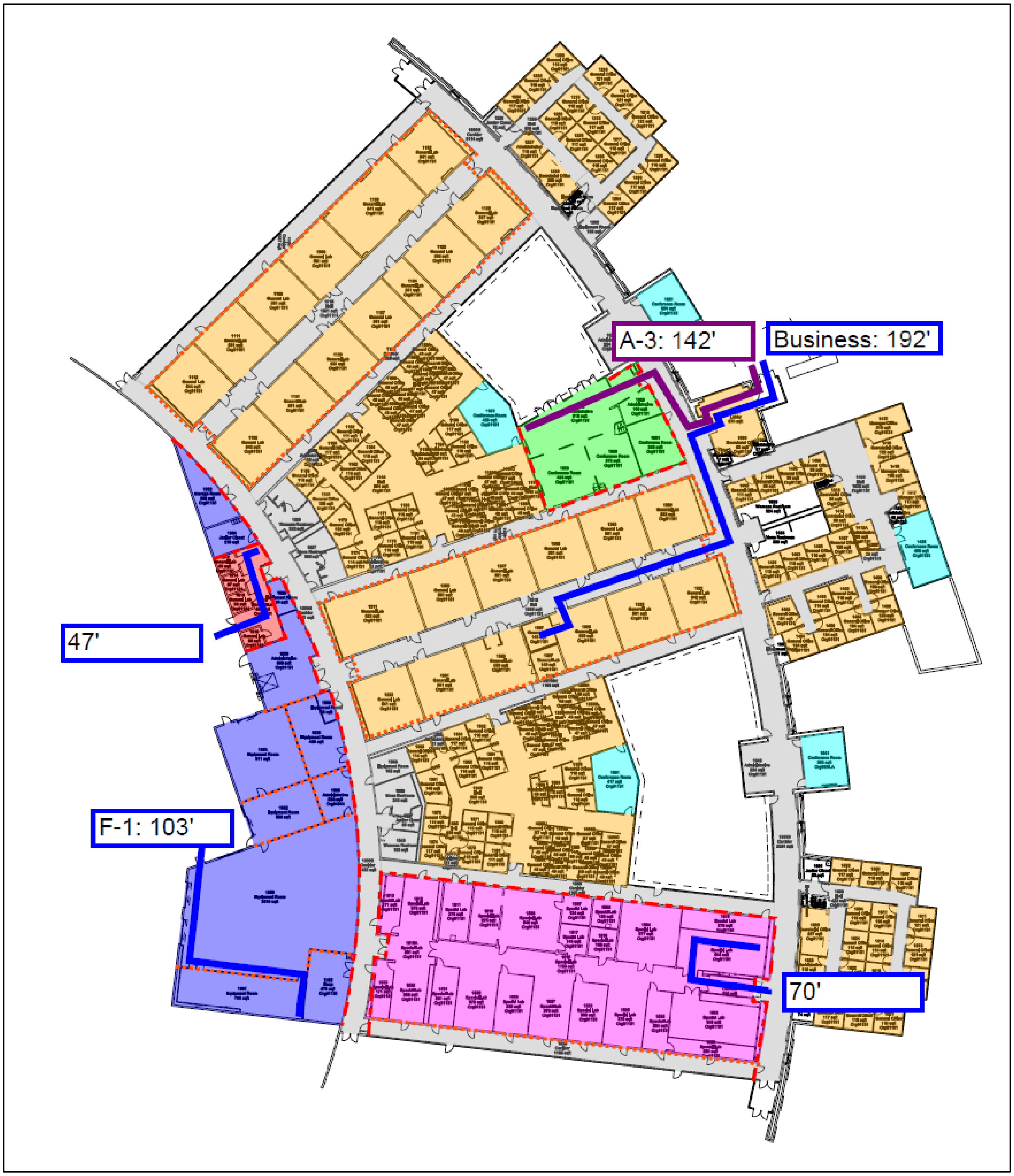


Figure 46 - Travel Distance Floor Plan

9.4 Appendix D: Fire Resistance Ratings

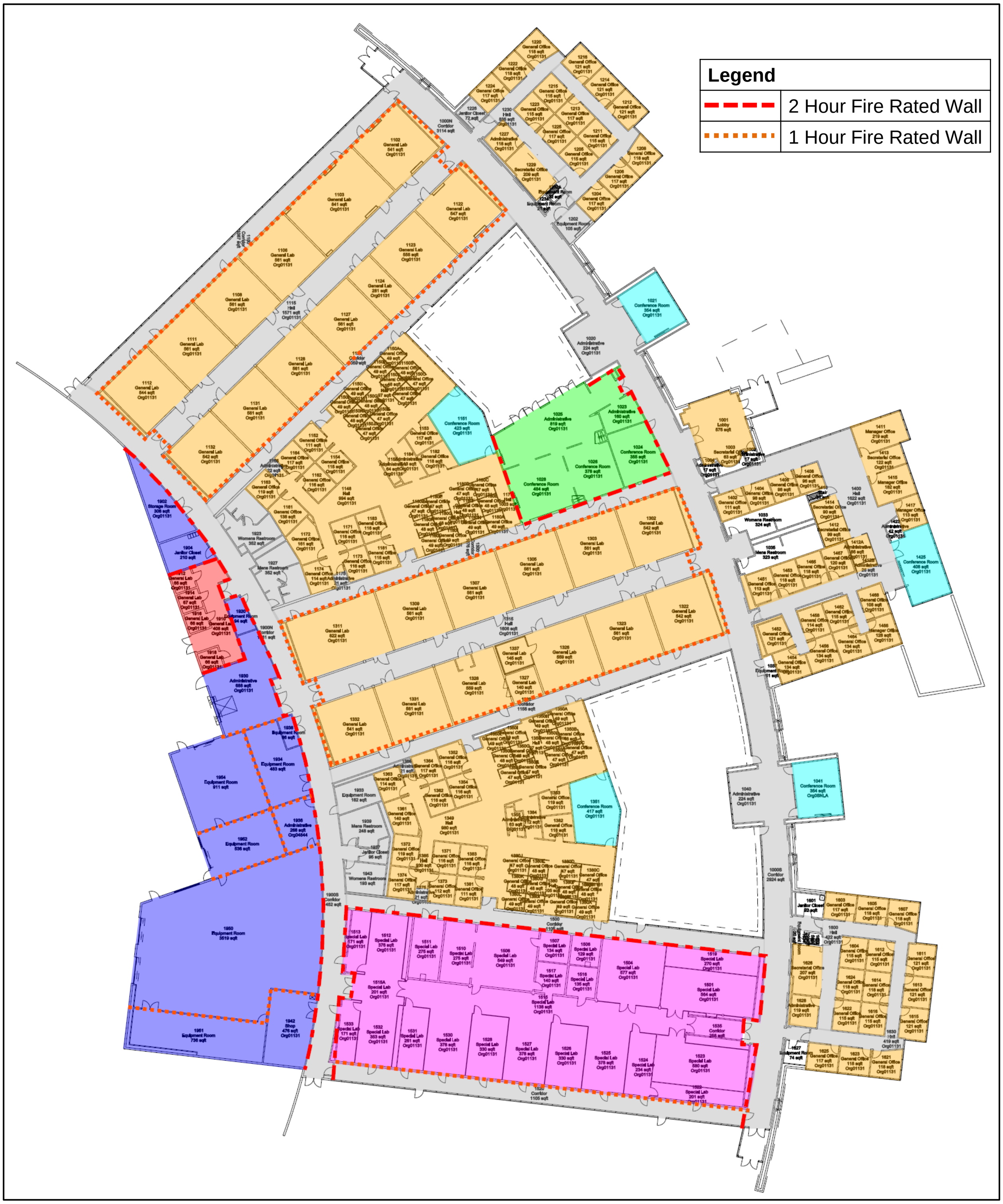


Figure 47 - Fire Rated Walls

9.5 Appendix E: Pathfinder Snapshots

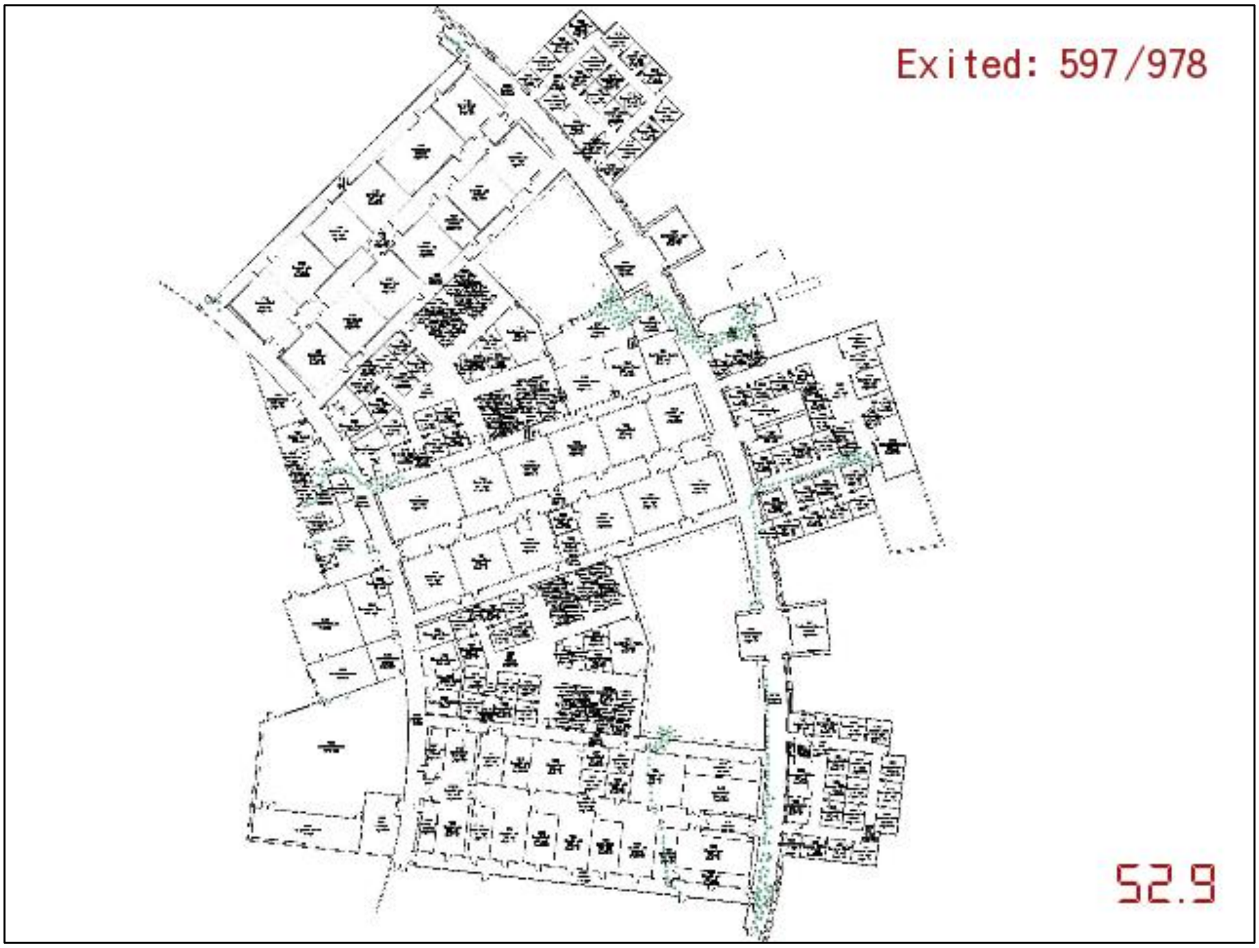


Figure 48 – Pathfinder: Simulated Evacuation

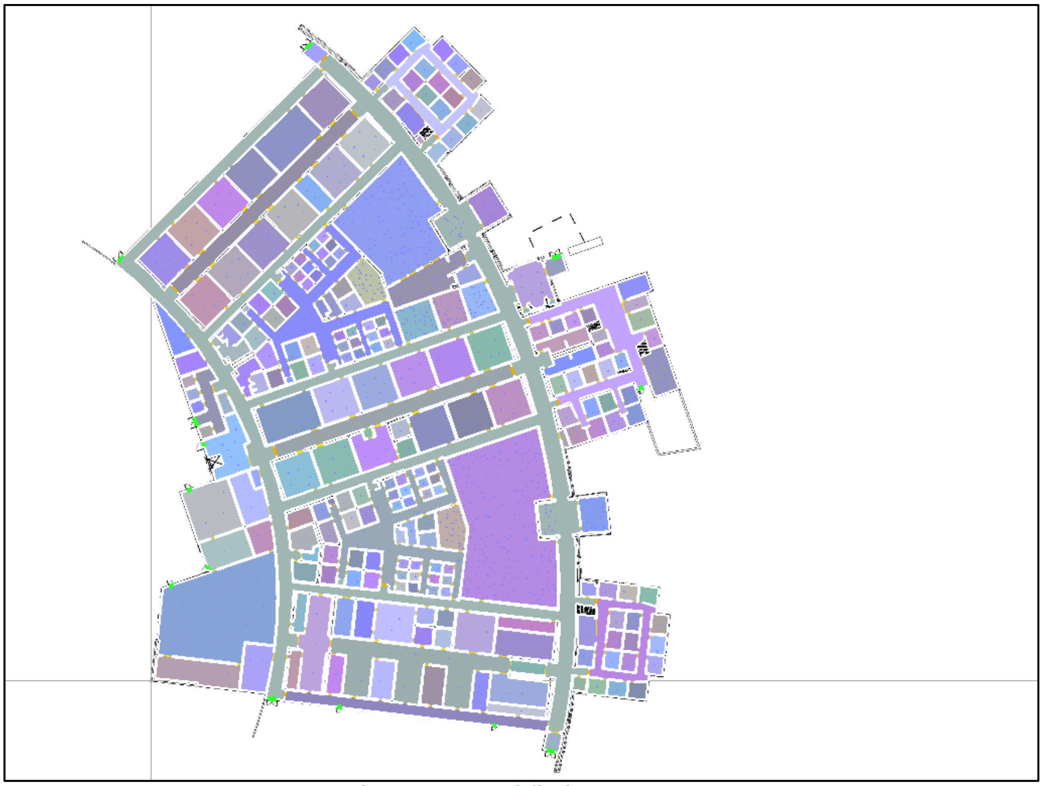


Figure 49 - Pathfinder: Spaces

Figure 50 - Pathfinder: Occupants 3-D Simulation

9.6 Appendix F: Automatic Sprinkler System

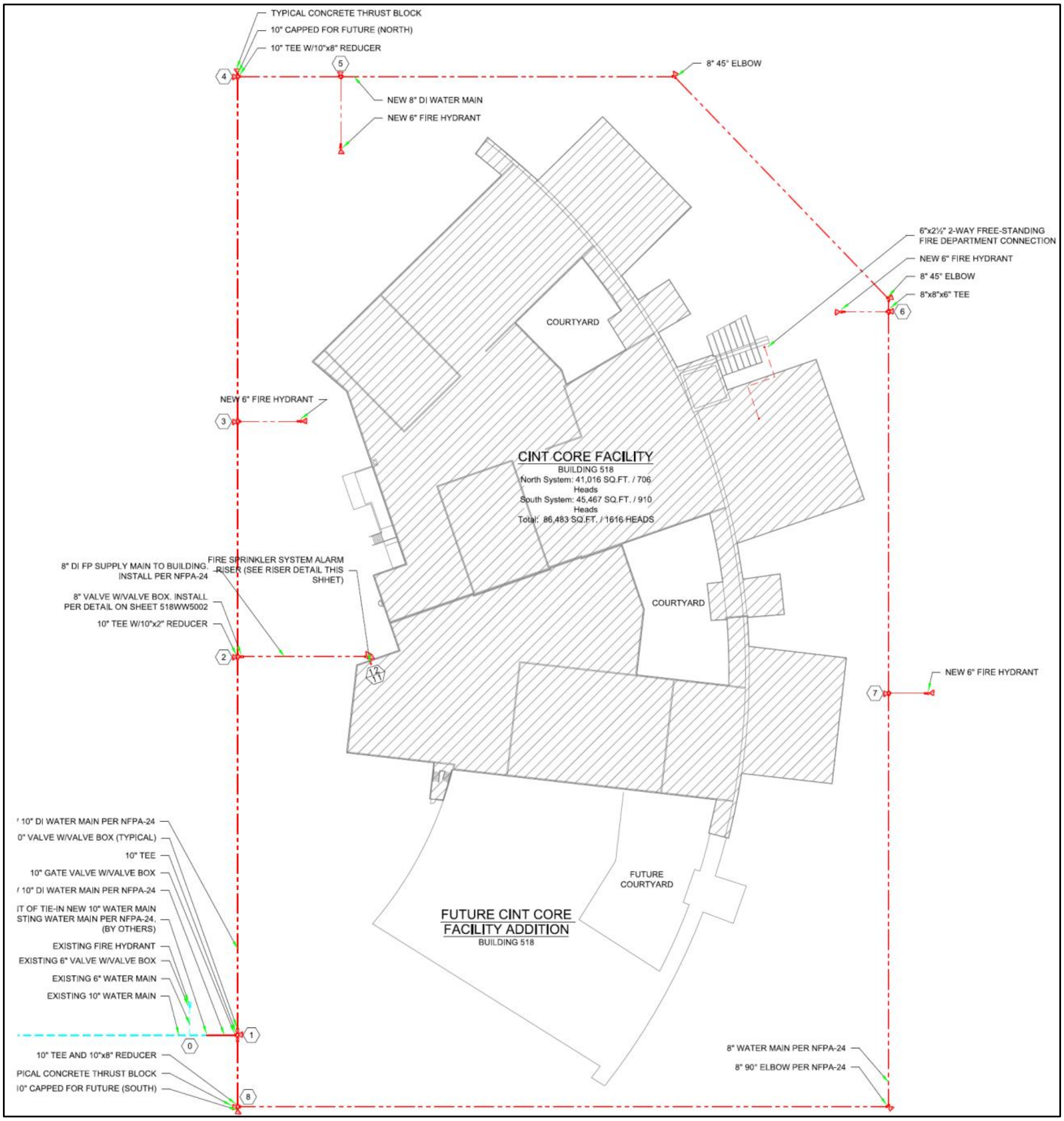


Figure 51 - Water Supply

The point of connection is located at Node 0. The risers connect to the looped fire line at node 2.

9.7 Appendix G: Sprinkler Head Detail

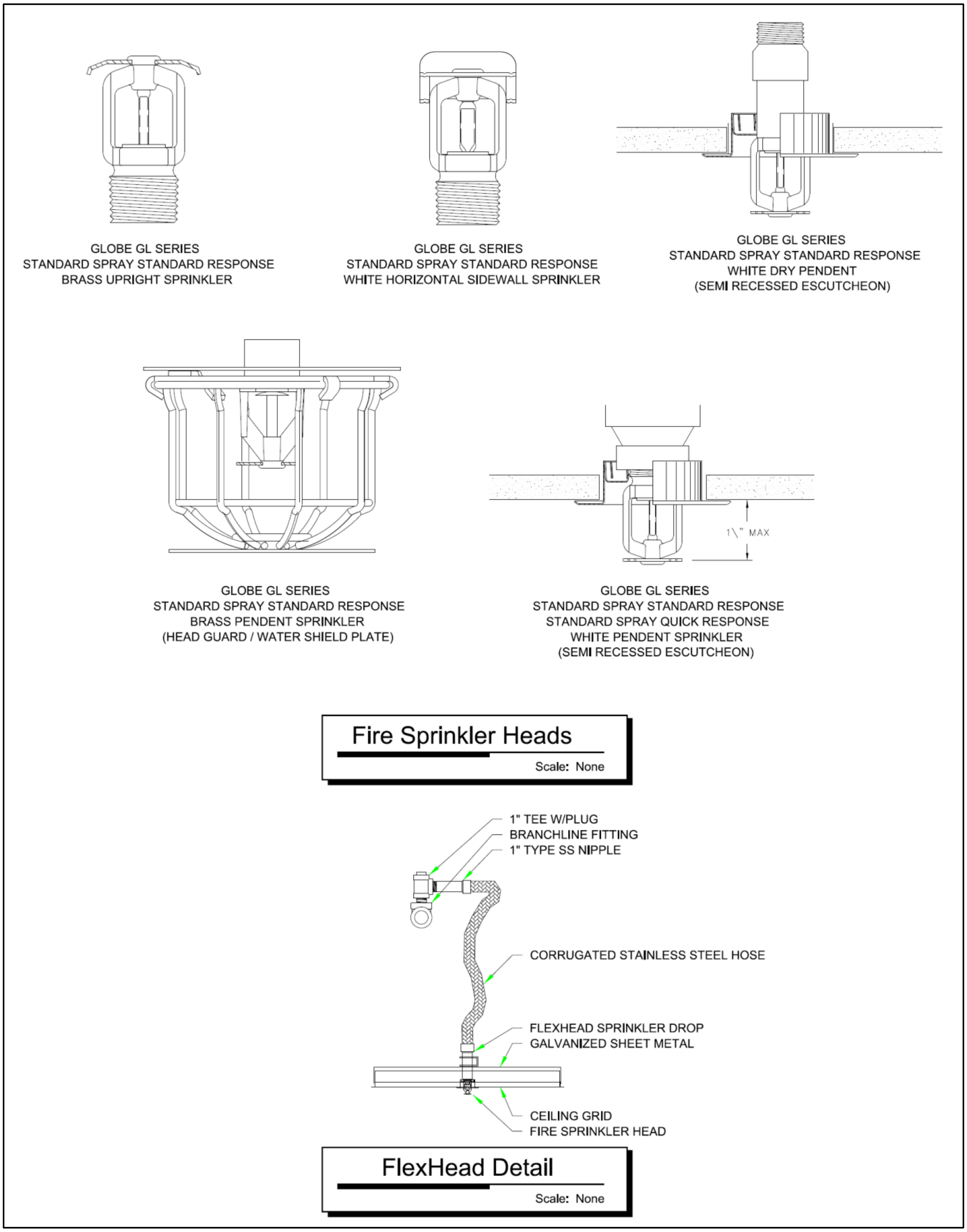


Figure 52 - Sprinkler Head Detail

9.8 Appendix H: Hydraulic Calculations

Figure 53 - Remote Areas

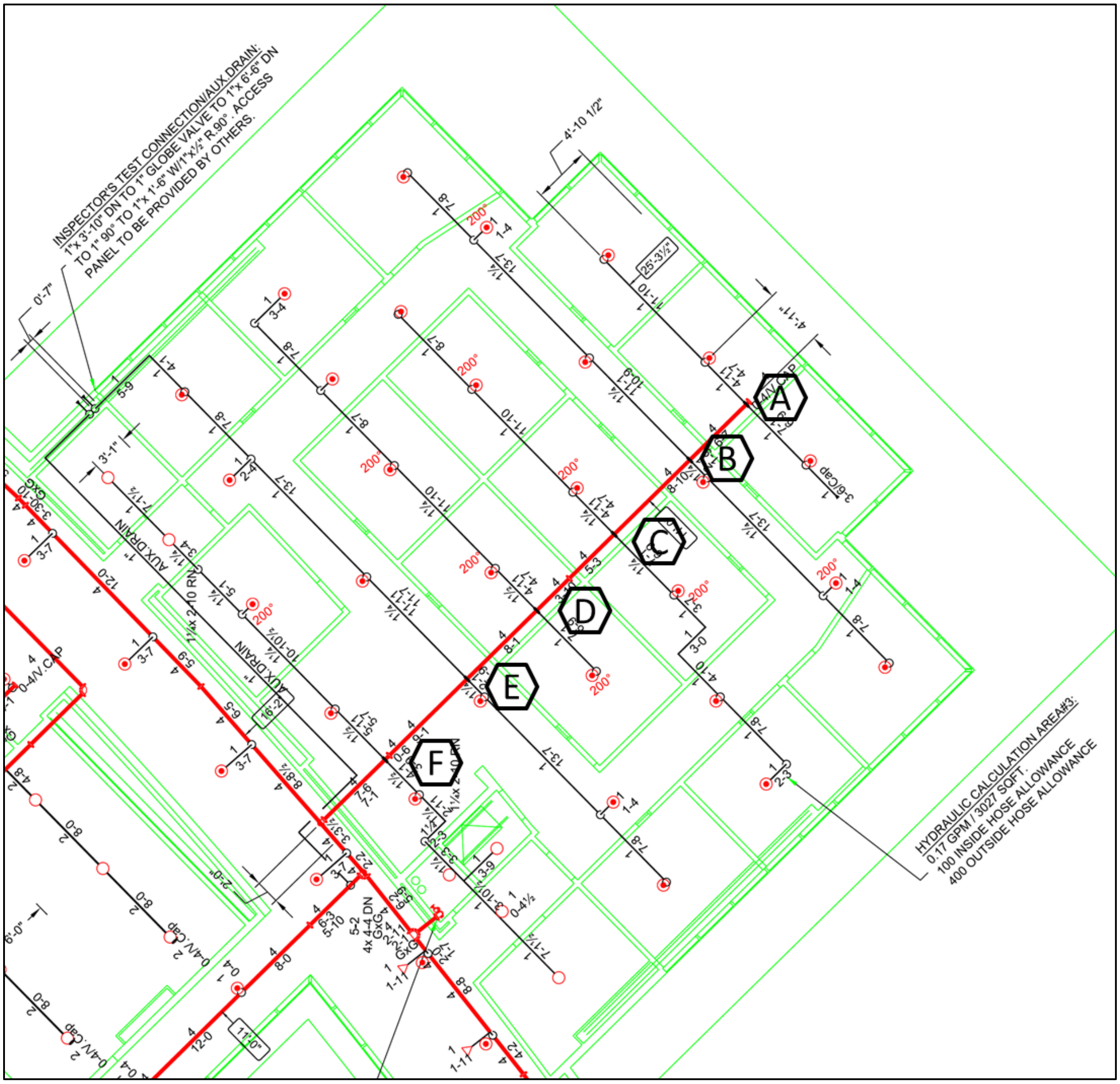


Figure 54 - Remote Area: Ordinary Hazard North System

Table 61 - Hydraulic Calculation of Ordinary Hazard North System

Project name:			0518 SNL CINT - Ordinary Hazard North System											Date:	Mar-14		
											L:	8.5	S:	10	D:	0.17	
p No.	Nozzle Ident and		Flow in gpm		Pipe size	Pipe Fittings and Devices	Equivalent Pipe Length		Friction loss (psi/ft)		Pressure Summary		Normal Pressur		Notes		Node
			q	14.5	1" Sch 40		L	11.83	C=	120	Pt	6.7	Pt		k=	5.6	
1	1	BL-1L			1.049		F	0			Pe		Pv			q = k * (Pt)^1/2	
			Q	14.5			T	11.83	pf	0.071	Pf	0.8	Pn		Pt=	6.7	
			q	15.3	1" Sch 40	T-5	L	4.9	C=	120	Pt	7.5	Pt		k=	5.6	
2	2	BL-1L			1.049		F	5			Pe		Pv				
			Q	29.8			T	9.9	pf	0.272	Pf	2.7	Pn				
		BL-1	q	0.0	1" Sch 40	T-5	L	14.3	C=	120	Pt	**10.2**	Pt		k=	0	
4		DN RN	q(3)	16.8	1.049		F	5			Pe	6.2	Pv			Pe=14.3*0.433	A
			Q	46.6			T	19.3	pf	0.623	Pf	12.0	Pn				
		CM to	q	0.0	4" Sch 10		L	6.6	C=	120	Pt	28.4	Pt		k=	0	
5		BL-2			4.26		F	0			Pe		Pv				B
			Q	46.6			T	6.6	pf	0.001	Pf	0.0	Pn				
		CM to	q	0.0	4" Sch 10		L	8.8	C=	120	Pt	**28.4**	Pt		k=	0	
8		BL-3	q(6,7)	152.6	4.26		F	0			Pe		Pv				C
			Q	199.2			T	8.8	pf	0.010	Pf	0.1	Pn				
		CM to	q	0.0	4" Sch 10		L	9.1	C=	120	Pt	**28.5**	Pt		k=	0	
11		BL-4	q(9,10)	142.2	4.26		F	0			Pe		Pv				D
			Q	341.4			T	9.1	pf	0.027	Pf	0.2	Pn				
		CM to	q	0.0	4" Sch 10		L	8.1	C=	120	Pt	**28.7**	Pt		k=	0.0	
14		BL-5	q(12,13)	101.3	4.26		F	0			Pe		Pv				E
			Q	442.8			T	8.1	pf	0.044	Pf	0.4	Pn				
		CM to	q	0.0	4" Sch 10		L	20	C=	120	Pt	**29.1**	Pt		k=	0.0	
17		BL-6	q(15,16)	140.0	4.26		F	0			Pe		Pv				F
			Q	582.8			T	20	pf	0.072	Pf	1.4	Pn				
		4"CM	q	0.0	4" Sch 10	T-20 (sch 10)	L	187	C=	120	Pt	**30.5**	Pt		k=	0.0	
20		to	q(18,19)	142.3	4.26	T-20 (sch 10)	F	79.2			Pe		Pv				G
		6"CM	Q	725.0		T-20 (sch 10)	T	266.2	pf	0.108	Pf	28.9	Pn				
		6"CM	q	0.0	6" Sch 10	E-14; 45-7	L	171	C=	120	Pt	59.4	Pt		k=	0.0	
8		to BOR			6.357	45-7; CV-32	F	83.16			Pe	4.8	Pv				H
			Q	**725.0**		GV-3	T	254.16	pf	0.015	Pf	3.9	Pn				
			q				L		C=		Pt	**68.1**	Pt				

Table 62 - Pressure Balance at Node A

Project name:			0518 SNL CINT - Pressure Balance at Node A										Date:				
											L:	8.5	S:	10	D:	0.17	
Step No.	Nozzle Ident and Location		Flow in gpm		Pipe size	Pipe Fittings and Devices	Equivalent Pipe Length		Friction loss (psi/ft)		Pressure Summary		Normal Pressure		Notes		
			q	14.5	1" Sch 40	T-5	L	7.1	C=	120	Pt	6.7	Pt		k=	5.6	
1	3	BL-1R			1.049		F	5			Pe		Pv			q(3) = A*D	
			Q	14.5			T	12.1	pf	0.071	Pf	0.9	Pn		K(BL-1R)=	5.3	
			q	16.8			L		C=		Pt	**7.5**	Pt		P(BL-1L)=	**10.2**	
	3	BL-1R					F				Pe		Pv			Since P(BL-1L)>P(BL-1R):	A
			Q	16.8			T		pf		Pf		Pn			Q_act(BL-1R)=K(BL-1R)*P(BL-1L)^(0.5)	

Table 63 - Pressure Balance at Node C

Project name:			0518 SNL CINT - Pressure Balance at Node C											Date:			
											L:	8.5	S:	10	D:	0.17	
Step No.	Nozzle Ident and Location		Flow in gpm		Pipe size	Pipe Fittings and Devices	Equivalent Pipe Length		Friction loss (psi/ft)		Pressure Summary		Normal Pressure			Notes	
			q	14.5	1" Sch 40		L	8.6	C=	120	Pt	6.7	Pt		k=	5.6	
9	1	BL-3L			1.049		F	0			Pe		Pv			q(9) = A*D	
			Q	14.5			T	8.6	pf	0.071	Pf	0.6	Pn				
			q	15.1	1" Sch 40		L	11.8	C=	120	Pt	7.3	Pt		k=	5.6	
9	2	BL-3L			1.049		F				Pe		Pv				
			Q	29.6			T	11.8	pf	0.268	Pf	3.2	Pn				
			q	18.1	1.25" Sch 40	T-6	L	4.9	C=	120	Pt	10.4	Pt		k=	5.6	
9	3	BL-3L			1.38		F	6			Pe		Pv				
			Q	47.6			T	10.9	pf	0.170	Pf	1.9	Pn		K(BL-3L)=	13.6	
			q	72.5			L		C=		Pt	**12.3**	Pt		P(CM-3)=	**28.5**	
9		BL-3L					F				Pe		Pv			Since P(CM-3)>P(BL-3L):	C
			Q	72.5			T		pf		Pf		Pn			Q_act(BL-3L)=K(BL-3L)*P(CM-3)^(0.5)	
			q	14.5	1" Sch 40	E-2	L	9.9	C=	120	Pt	6.7	Pt		k=	5.6	
10	1	BL-3R			1.049		F	2			Pe		Pv			q(10) = A*D	
			Q	14.5			T	11.9	pf	0.071	Pf	0.8	Pn				
			q	15.3	1" Sch 40	E-2	L	11.4	C=	120	Pt	7.5	Pt		k=	5.6	
10	2	BL-3R			1.049	E-2	F	4			Pe		Pv				
			Q	29.8			T	15.4	pf	0.272	Pf	4.2	Pn				
			q	19.2	1.25" Sch 40	T-6	L	7.1	C=	120	Pt	11.7	Pt		k=	5.6	
10	3	BL-3R			1.38		F	6			Pe		Pv				
			Q	48.9			T	13.1	pf	0.179	Pf	2.3	Pn		K(BL-3R)=	13.1	
			q	69.7			L		C=		Pt	**14.0**	Pt		P(CM-3)=	**28.5**	
10		BL-3R					F				Pe		Pv			Since P(CM-3)>P(BL-3R):	C
			Q	69.7			T		pf		Pf		Pn			Q_act(BL-3R)=K(BL-3R)*P(CM-3)^(0.5)	

Table 64 - Pressure Balance at Node D

Project name:			0518 SNL CINT - Pressure Balance at Node D											Date:			
											L:	8.5	S:	10	D:	0.17	
Step No.	Nozzle Ident and Location		Flow in gpm		Pipe size	Pipe Fittings and Devices	Equivalent Pipe Length		Friction loss (psi/ft)		Pressure Summary		Normal Pressure			Notes	
			q	14.5	1" Sch 40	E-2	L	11	C=	120	Pt	6.7	Pt		k=	5.6	
12	1	BL-4L			1.049		F	2			Pe		Pv			q(12) = A*D	
			Q	14.5			T	13	pf	0.071	Pf	0.9	Pn				
			q	15.4	1" Sch 40		L	8.6	C=	120	Pt	7.6	Pt		k=	5.6	
12	2	BL-4L			1.049		F				Pe		Pv				
			Q	29.9			T	8.6	pf	0.273	Pf	2.4	Pn				
			q	17.7	1.25" Sch 40		L	11.8	C=	120	Pt	9.9	Pt		k=	5.6	
12	2	BL-4L			1.38		F				Pe		Pv				
			Q	47.5			T	11.8	pf	0.170	Pf	2.0	Pn				
			q	19.3	1.5" Sch 40	T-8	L	4.9	C=	120	Pt	11.9	Pt		k=	5.6	
12	3	BL-4L			1.61		F	8			Pe		Pv				
			Q	49.2			T	12.9	pf	0.085	Pf	1.1	Pn		K(BL-4L)=	13.6	
			q	73.1			L		C=		Pt	**13.0**	Pt		P(CM-4)=	**28.7**	
12	3	BL-4L					F				Pe		Pv			Since P(CM-4)>P(BL-4L):	D
			Q	73.1			T		pf		Pf		Pn			Q_act(BL-4L)=K(BL-4L)*P(CM-4)^(0.5)	
			q	14.5	1" Sch 40	T-5	L	7.1	C=	120	Pt	6.7	Pt		k=	5.6	
13	1	BL-4R			1.049		F	5			Pe		Pv				
			Q	14.5			T	12.1	pf	0.071	Pf	0.9	Pn		K(BL-4R)=	5.3	
			q	28.2			L		C=		Pt	**7.5**	Pt		P(CM-4)=	**28.7**	
13		BL-4R					F				Pe		Pv			Since P(CM-4)>P(BL-4R):	D
			Q	28.2			T		pf		Pf		Pn			Q_act(BL-4R)=K(BL-4R)*P(CM-4)^(0.5)	

Table 65 - Pressure Balance at Node E

Project name:			0518 SNL CINT - Pressure Balance at Node E											Date:			
											L:	8.5	S:	10	D:	0.17	
Step No.	Nozzle Ident and Location		Flow in gpm		Pipe size	Pipe Fittings and Devices	Equivalent Pipe Length		Friction loss (psi/ft)		Pressure Summary		Normal Pressure			Notes	
			q	14.5	1" Sch 40		L	7.7	C=	120	Pt	6.7	Pt		k=	5.6	
15	1	BL-5L			1.049		F	0			Pe		Pv			q(9) = A*D	
			Q	14.5			T	7.7	pf	0.071	Pf	0.5	Pn				
			q	15.0	1" Sch 40	E-2	L	15.9	C=	120	Pt	7.2	Pt		k=	5.6	
15	2	BL-3L			1.049		F	2			Pe		Pv				
			Q	29.5			T	17.9	pf	0.267	Pf	4.8	Pn				
			q	19.4	1.25" Sch 40	T-6	L	11.9	C=	120	Pt	12.0	Pt		k=	5.6	
15	3	BL-3L			1.38		F	6			Pe		Pv				
			Q	48.9			T	17.9	pf	0.179	Pf	3.2	Pn		K(BL-5L)=	12.5	
			q	67.6			L		C=		Pt	**15.2**	Pt		P(CM-5)=	**29.1**	
15		BL-3L					F				Pe		Pv			Since P(CM-5)>P(BL-5L):	E
			Q	67.6			T		pf		Pf		Pn			Q_act(BL-5L)=K(BL-5L)*P(CM-5)^(0.5)	
			q	14.5	1" Sch 40		L	7.7	C=	120	Pt	6.7	Pt		k=	5.6	
16	1	BL-5R			1.049		F	0			Pe		Pv			q(10) = A*D	
			Q	14.5			T	7.7	pf	0.071	Pf	0.5	Pn				
			q	15.0	1" Sch 40	E-2	L	14.9	C=	120	Pt	7.2	Pt		k=	5.6	
16	2	BL-5R			1.049		F	2			Pe		Pv				
			Q	29.5			T	16.9	pf	0.267	Pf	4.5	Pn				
			q	19.2	1.25" Sch 40	T-6	L	2.1	C=	120	Pt	11.7	Pt		k=	5.6	
16	3	BL-5R			1.38		F	6			Pe		Pv				
			Q	48.7			T	8.1	pf	0.177	Pf	1.4	Pn		K(BL-5R)=	13.4	
			q	72.4			L		C=		Pt	**13.2**	Pt		P(CM-5)=	**29.1**	
16		BL-5R					F				Pe		Pv			Since P(CM-5)>P(BL-5R):	E
			Q	72.4			T		pf		Pf		Pn			Q_act(BL-5R)=K(BL-5R)*P(CM-5)^(0.5)	

Table 66 - Pressure Balance at Node F

Project name:			0518 SNL CINT - Pressure Balance at Node F											Date:			
											L:	8.5	S:	10	D:	0.17	
Step No.	Nozzle Ident and Location		Flow in gpm		Pipe size	Pipe Fittings and Devices	Equivalent Pipe Length		Friction loss (psi/ft)		Pressure Summary		Normal Pressure			Notes	
			q	14.5	1" Sch 40		L	7.1	C=	120	Pt	6.7	Pt		k=	5.6	
18	1	BL-6L			1.049		F	0			Pe		Pv			q(9) = A*D	
			Q	14.5			T	7.1	pf	0.071	Pf	0.5	Pn				
			q	15.0	1.25" Sch 40	E-2	L	11.25	C=	120	Pt	7.2	Pt		k=	5.6	
18	2	BL-6L			1.38	E-2	F	4			Pe	1.2	Pv				
			Q	29.4			T	15.25	pf	0.070	Pf	1.1	Pn				
			q	17.2	1.25" Sch 40		L	10.9	C=	120	Pt	9.4	Pt		k=	5.6	
18	3	BL-6L			1.38		F	0			Pe		Pv				
			Q	46.6			T	10.9	pf	0.164	Pf	1.8	Pn				
			q	18.8	1.5" Sch 40	T-8	L	5.9	C=	120	Pt	11.2	Pt		k=	5.6	
18	4	BL-6L			1.61		F	8			Pe		Pv				
			Q	48.2			T	13.9	pf	0.082	Pf	1.1	Pn		K(BL-6L)=	13.7	
			q	75.7			L		C=		Pt	**12.4**	Pt		P(CM-6)=	**30.5**	
18		BL-6L					F				Pe		Pv			Since P(CM-6)>P(BL-6L):	F
			Q	75.7			T		pf		Pf		Pn			Q_act(BL-6L)=K(BL-6L)*P(CM-6)^(0.5)	
			q	14.5	1" Sch 40		L	7.1	C=	120	Pt	6.7	Pt		k=	5.6	
19	1	BL-6R			1.049		F	0			Pe		Pv			q(10) = A*D	
			Q	14.5			T	7.1	pf	0.071	Pf	0.5	Pn				
			q	15.0	1" Sch 40	E-2	L	4.25	C=	120	Pt	7.2	Pt		k=	5.6	
19	2	BL-6R			1.049		F	2			Pe		Pv				
			Q	29.4			T	6.25	pf	0.266	Pf	1.7	Pn				
			q	16.6	1" Sch 40	E-2	L	3.75	C=	120	Pt	8.8	Pt		k=	5.6	
19	3	BL-6R			1.049		F	2			Pe		Pv				
			Q	46.1			T	5.75	pf	0.609	Pf	3.5	Pn				
			q	19.7	1.25" Sch 40	E-3	L	11.25	C=	120	Pt	12.3	Pt		k=	5.6	
19	4	BL-6R			1.38	E-3	F	9			Pe		Pv				
			Q	65.7		E-3	T	20.25	pf	0.309	Pf	6.3	Pn				
			q	24.1	1.5" Sch 40	T-8	L	4.1	C=	120	Pt	18.6	Pt		k=	5.6	
19	5	BL-6R			1.61		F	8			Pe		Pv				
			Q	53.6			T	12.1	pf	0.100	Pf	1.2	Pn		K(BL-6R)=	12.0	
			q	66.5			L		C=		Pt	**19.8**	Pt		P(CM-6)=	**30.5**	
19		BL-6R					F				Pe		Pv			Since P(CM-6)>P(BL-6R):	F
			Q	66.5			T		pf		Pf		Pn			Q_act(BL-6R)=K(BL-6R)*P(CM-6)^(0.5)	

9.9 Appendix I: Flow Test Summary Sheet

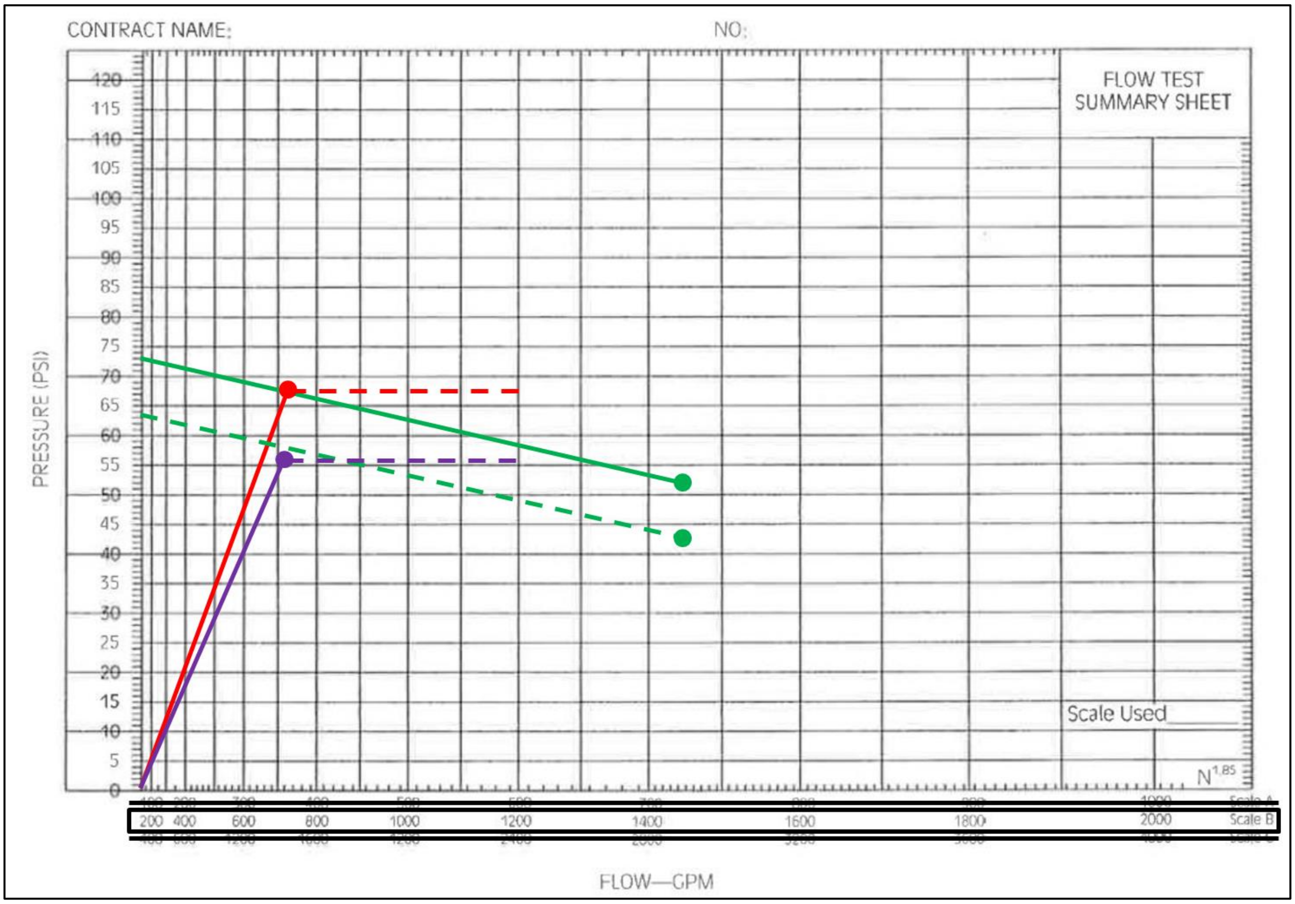


Figure 55 - Flow Test Summary

**The solid green line represents the water supply. The dashed green line is the 85 percent water supply limit set by Sandia Spec 15310. The red line is the sprinkler demand according to the manual calculations performed in "*Appendix H: Hydraulic Calculations*". The red dashed line is the 500 gpm hose stream allowance for the manually calculated demand. The purple line is the sprinkler demand according to the designer's calculations. The dashed purple line is the 500 gpm hose stream allowance for the designer's demand.*

9.10 Appendix J: Fire Alarm System

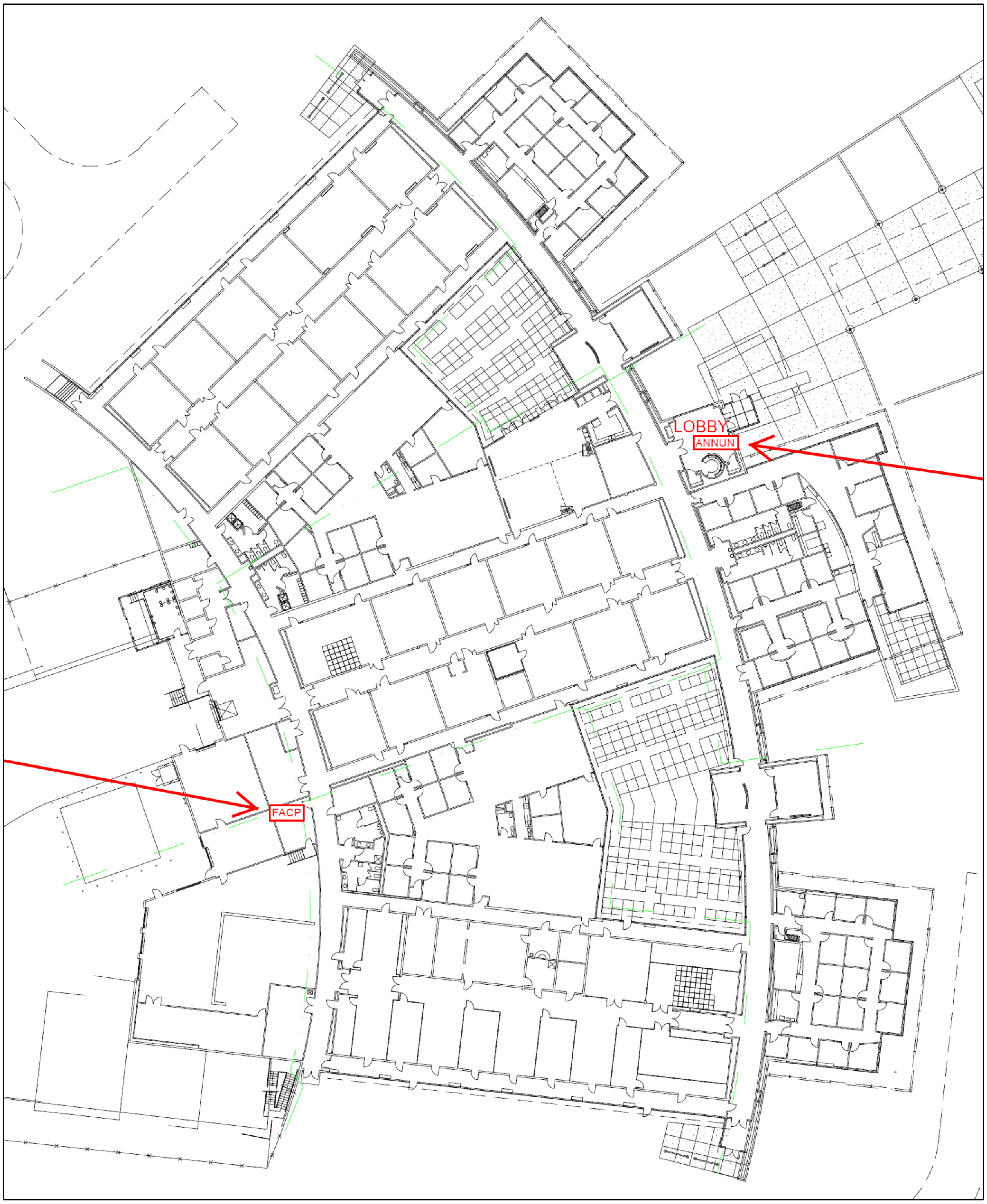


Figure 56 - FACP Location

9.11 Appendix K: Fire Alarm System Location and Spacing

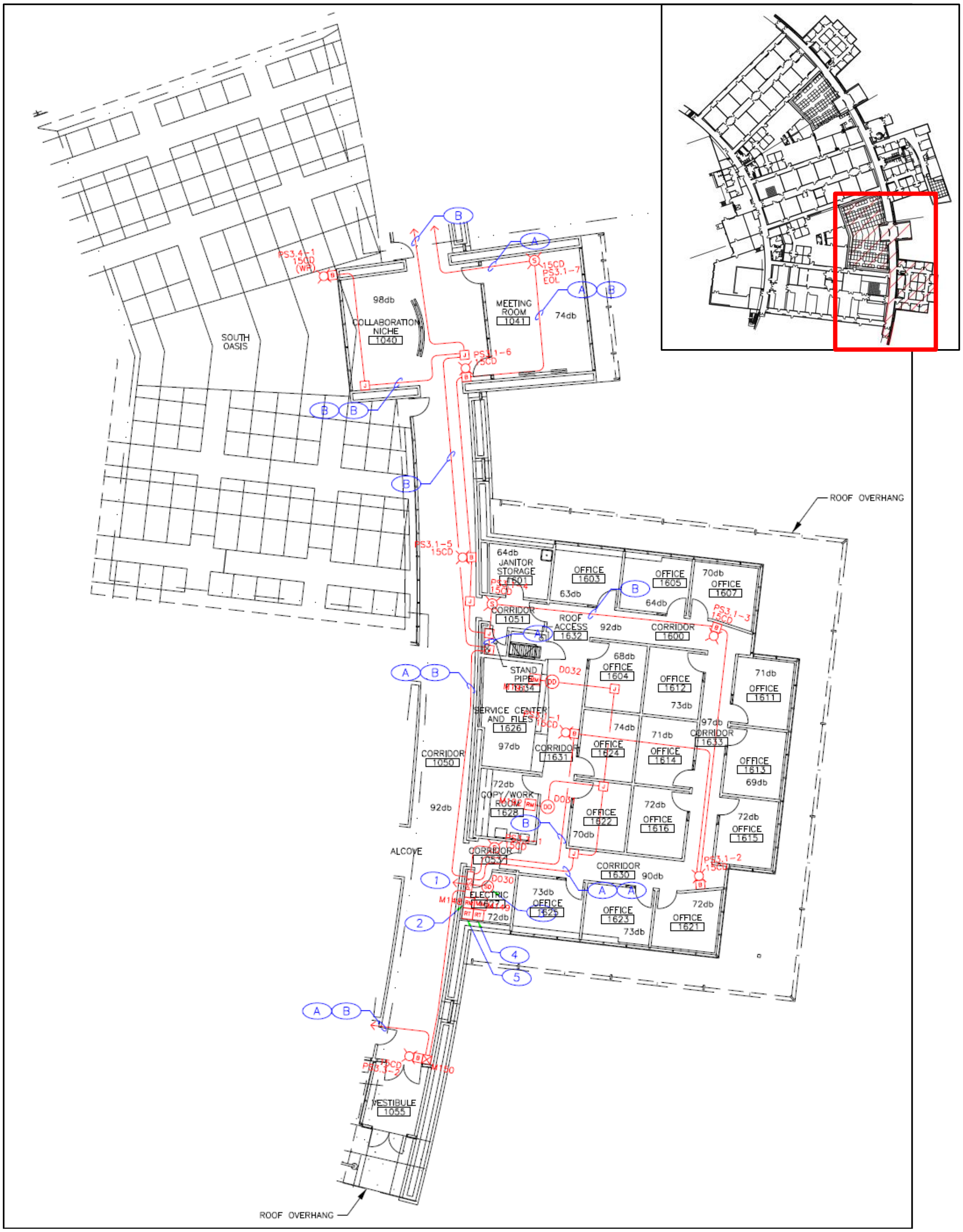


Figure 57 - Fire Alarm System (SE Region)

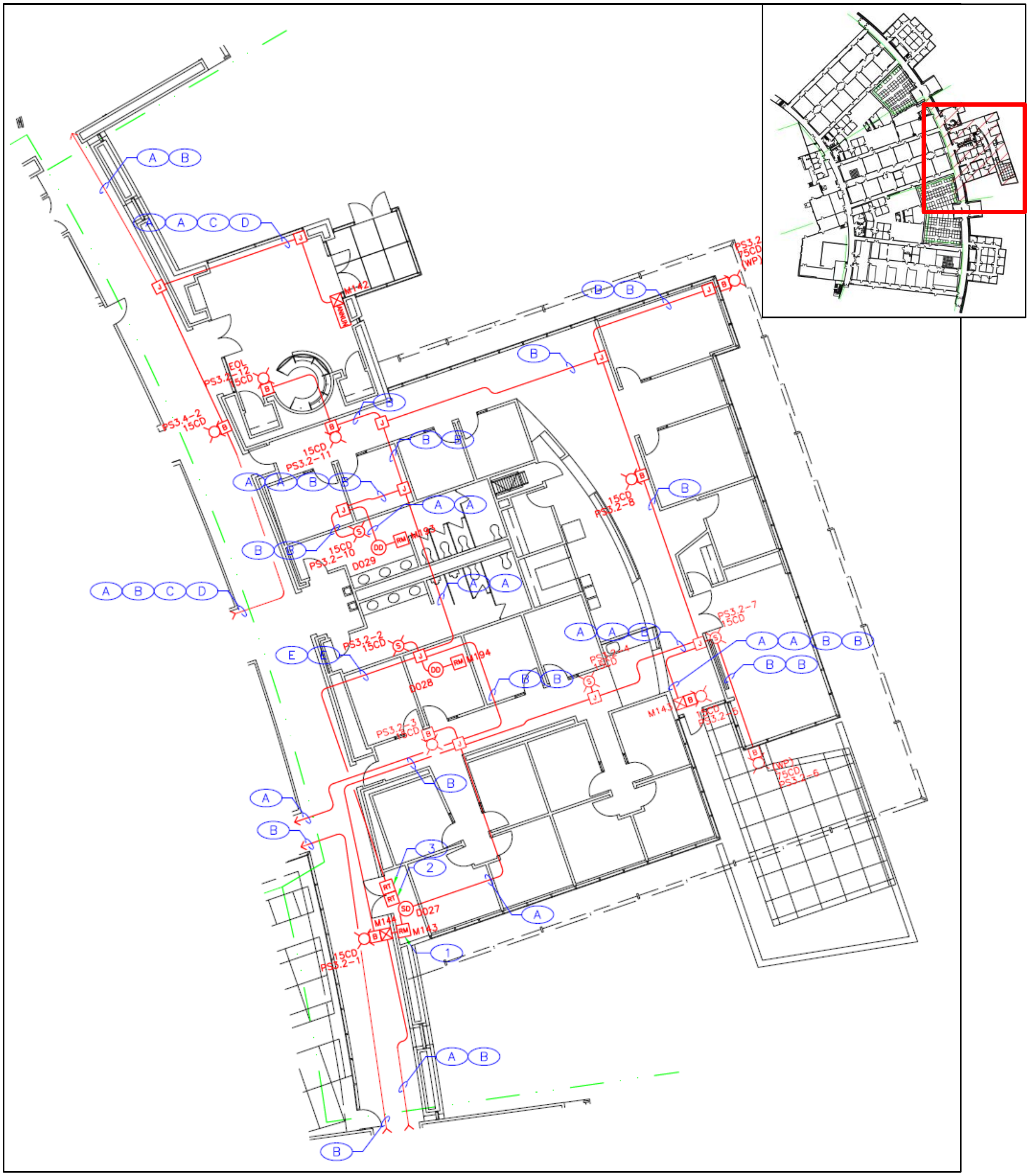


Figure 58 - Fire Alarm System (E Region)

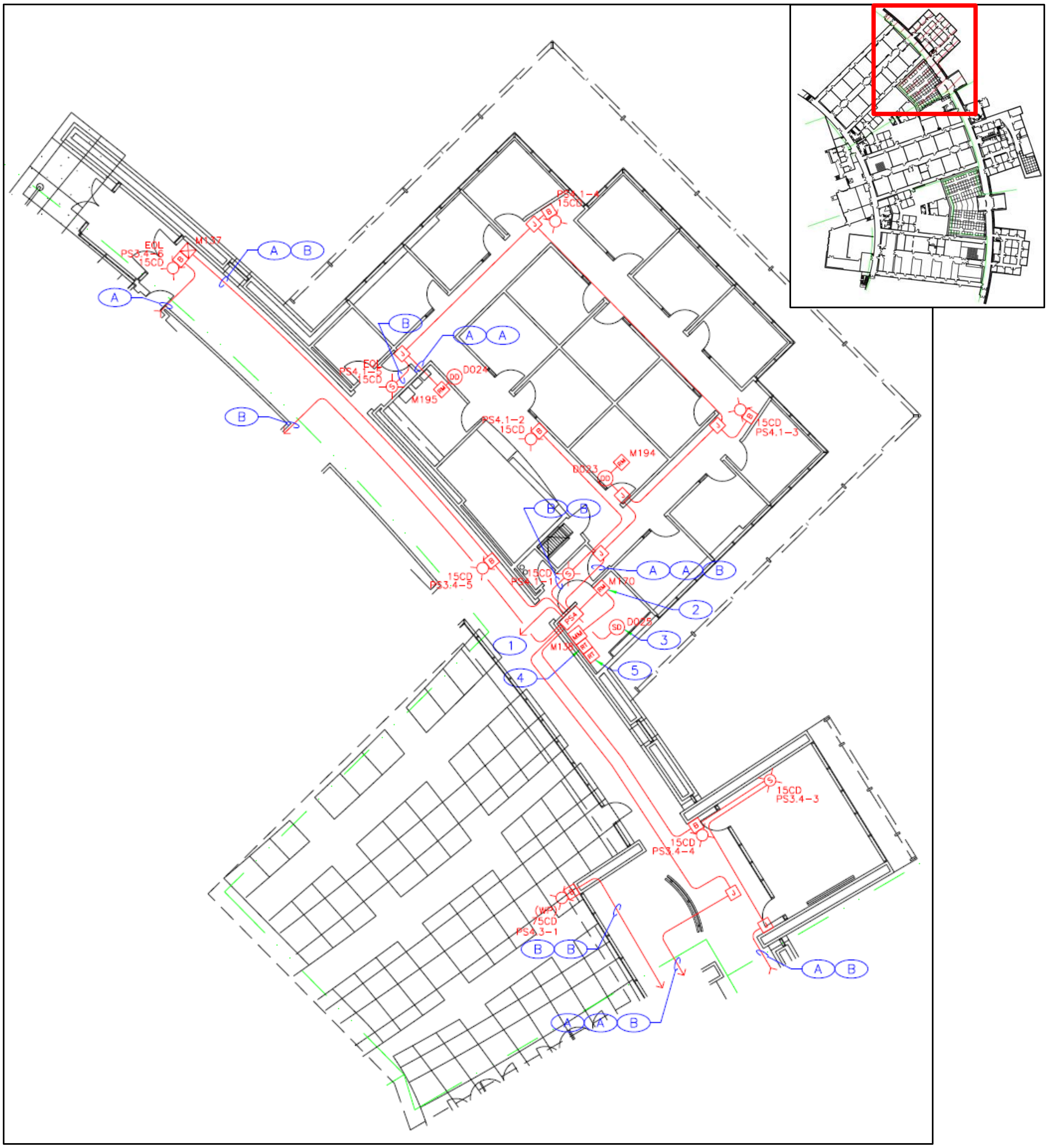


Figure 59 - Fire Alarm System (NE Region)

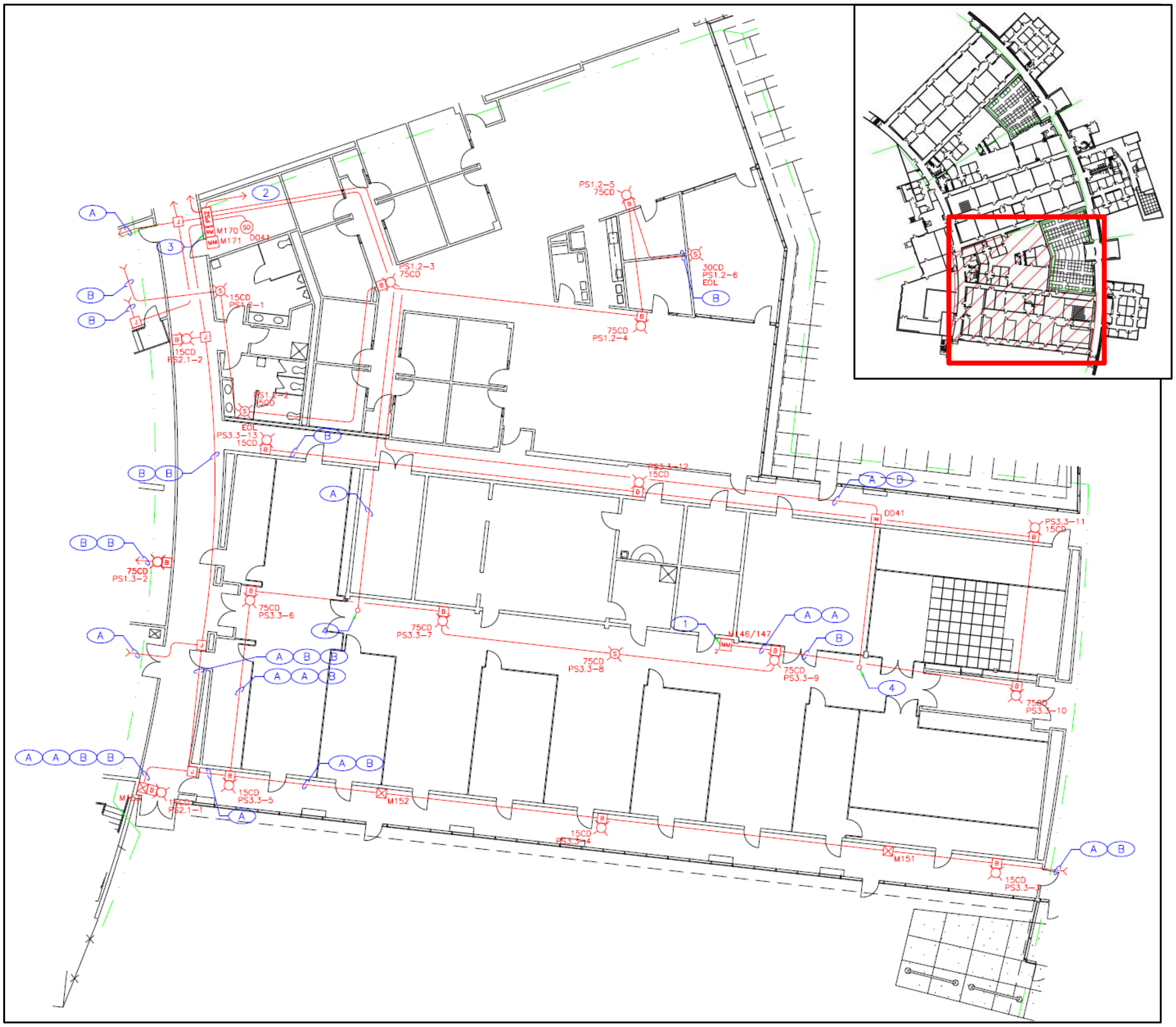


Figure 60 - Fire Alarm System (S Region)

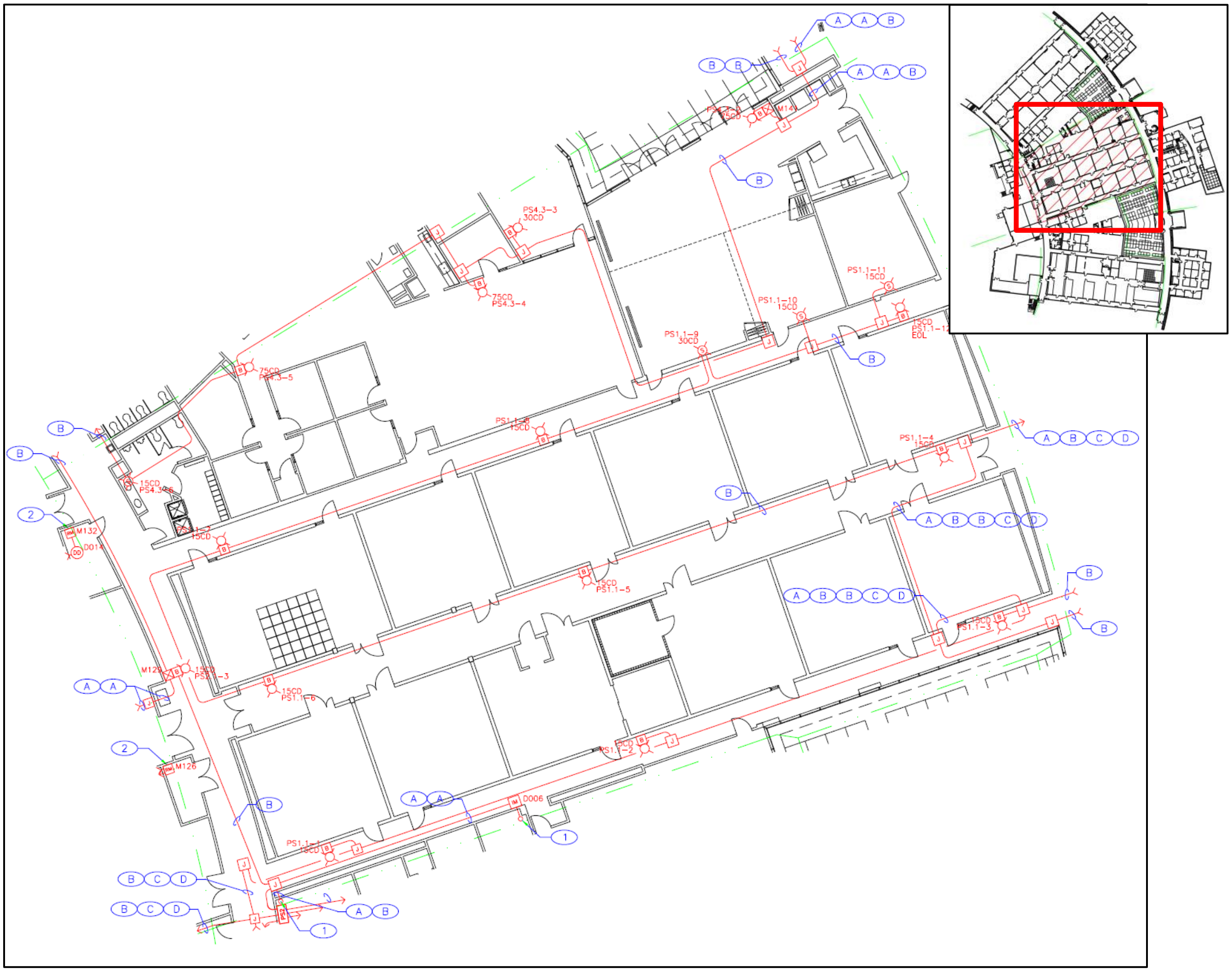


Figure 61 - Fire Alarm System (Center Region)

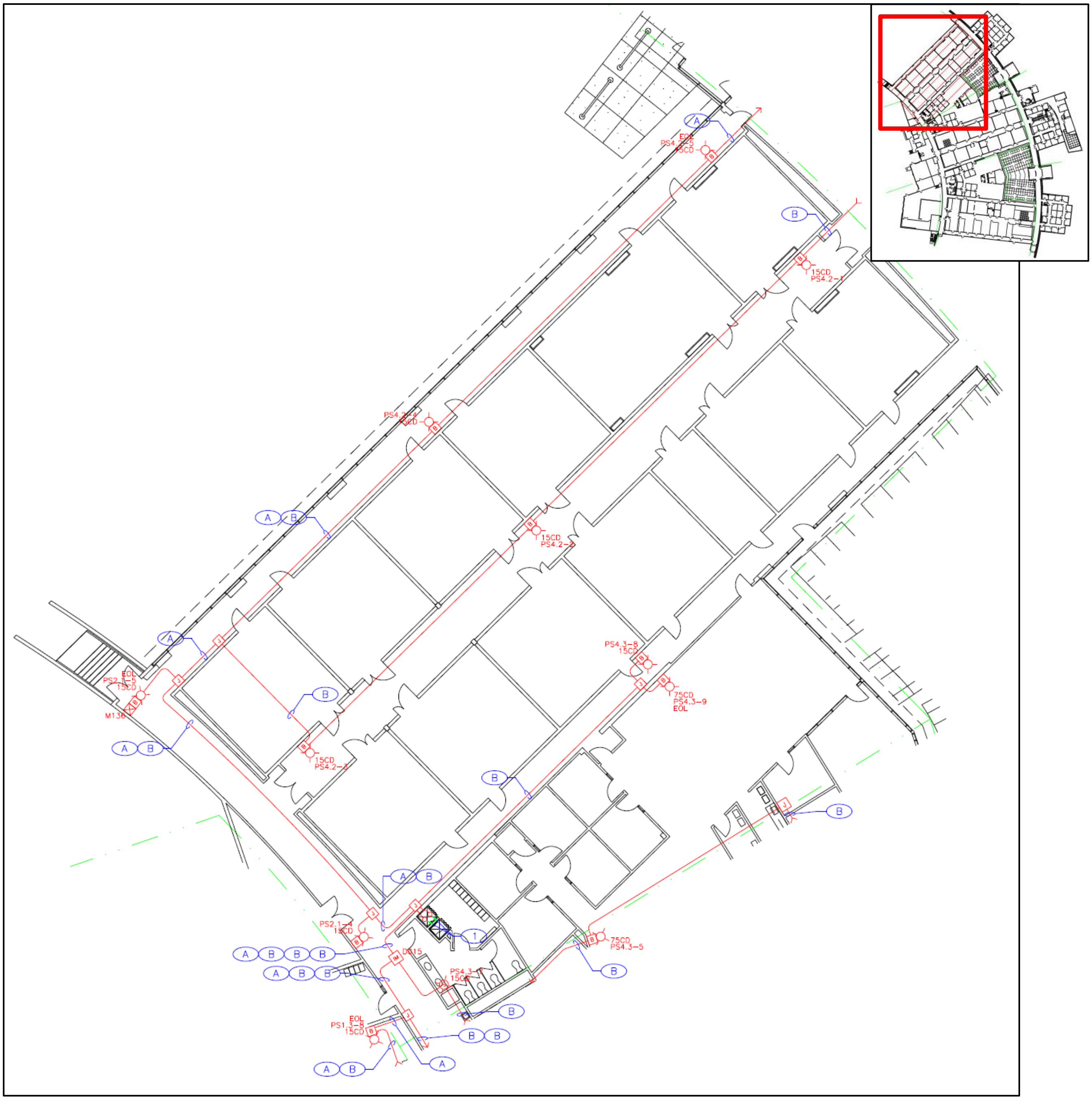


Figure 62 - Fire Alarm System (N Region)

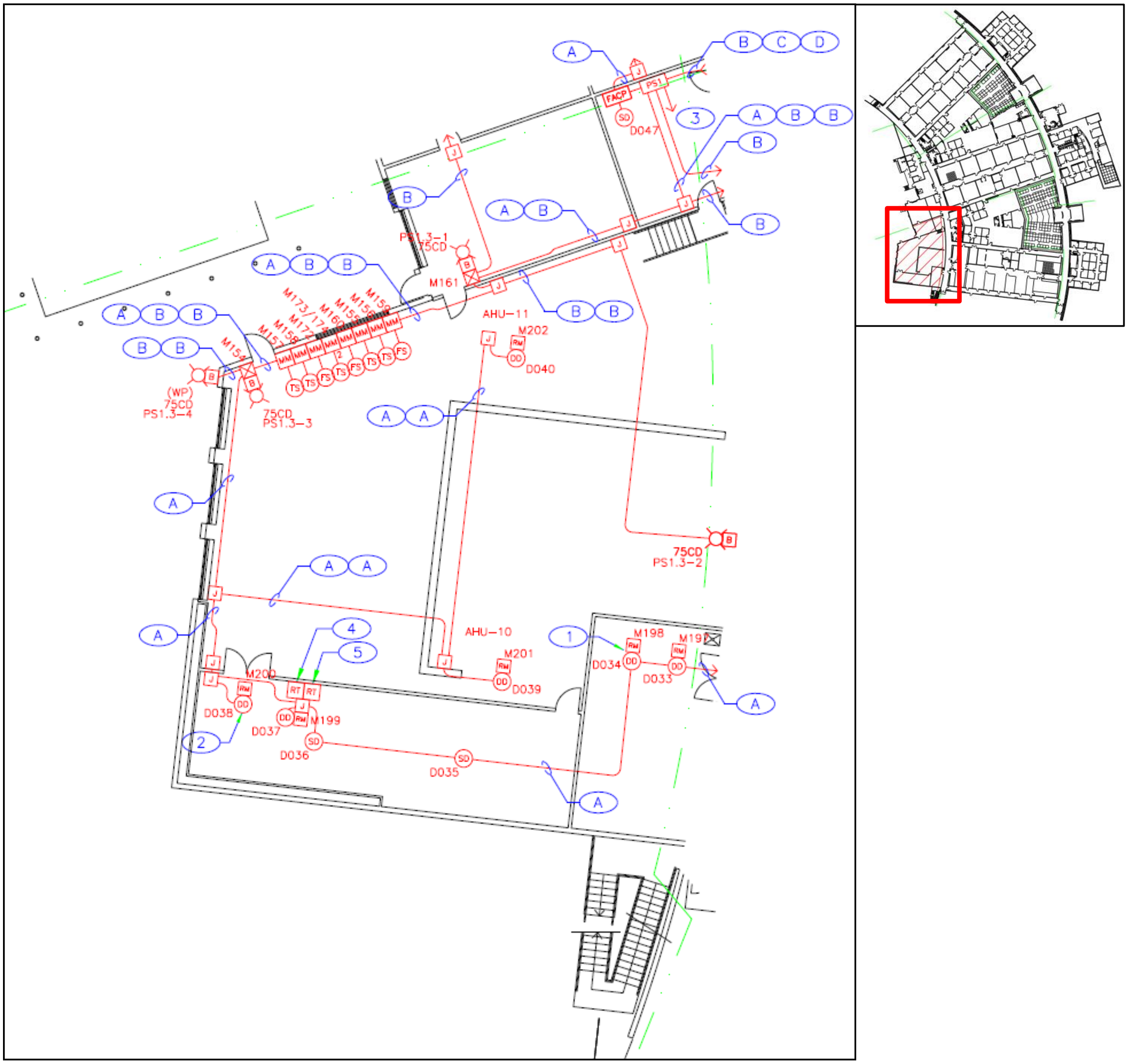


Figure 63 - Fire Alarm System (SW Region)

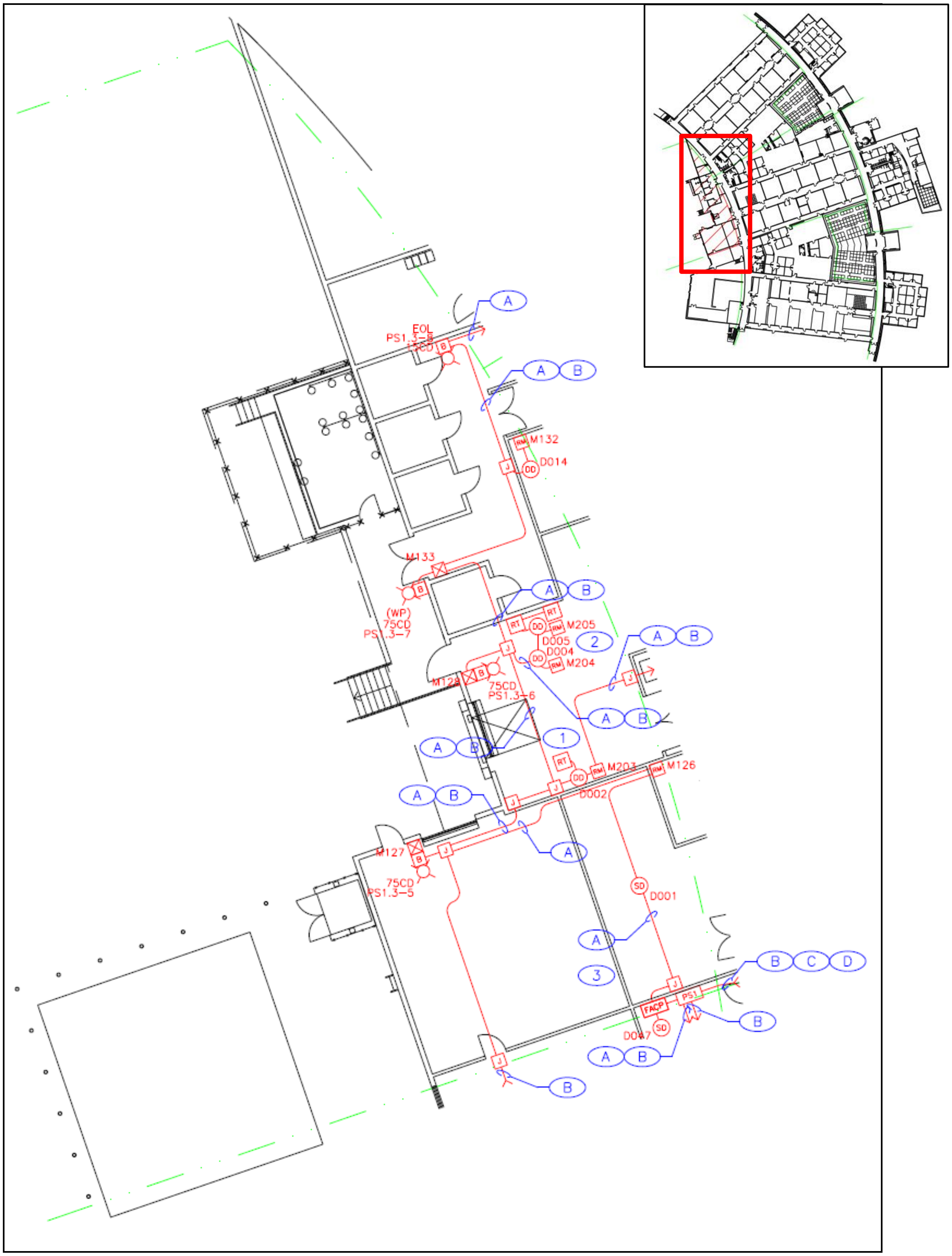


Figure 64 - Fire Alarm System (W Region)

9.12 Appendix L: Wheelock Horn/Strobe

Figure 65 - Wheelock MT Horn Strobe

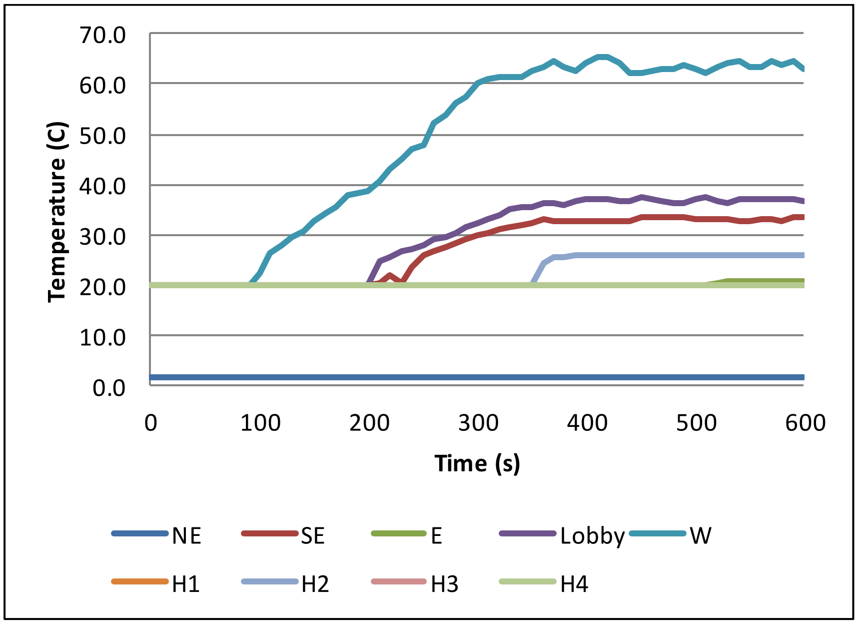
Table 67 - Horn Current and Sound Pressure Ratings

	Table 1: dBA and Current Ratings for Multitone Audible Portion															
	RMS Current (amps)										dBA @ 10ft (UL Reverberant)					
	24 VDC				12 VDC				120 VAC		24 VDC		12 VDC		120 VAC	
	HI Output		STD Output		HI Output		STD Output		HI Output	STD Output	HI Output	STD Output	HI Output	STD Output	HI Output	STD Output
	@ 24 VDC	UL max*	@ 24 VDC	UL max*	@ 24 VDC	UL max*	@ 24 VDC	UL max*	UL max*	UL max*						
Horn	0.074	0.108	0.033	0.044	0.145	0.176	0.023	0.034	0.050	0.042	92	87	90	77	85	82
Bell	0.040	0.053	0.018	0.024	0.077	0.095	0.014	0.020	0.041	0.039	86	80	85	69	82	75
March Time Horn	0.067	0.104	0.033	0.038	0.109	0.142	0.023	0.034	0.050	0.040	89	84	89	74	85	79
Code-3 Horn	0.069	0.091	0.026	0.035	0.100	0.142	0.023	0.034	0.050	0.042	88	83	88	73	82	75
Code-3 Tone	0.061	0.075	0.026	0.035	0.088	0.105	0.015	0.021	0.042	0.040	85	80	84	70	79	75
Slow Whoop	0.069	0.098	0.028	0.037	0.100	0.142	0.025	0.035	0.050	0.042	90	89	89	75	85	82
Siren	0.080	0.104	0.027	0.036	0.122	0.152	0.021	0.030	0.045	0.041	89	84	89	75	85	82
HI/LO	0.044	0.057	0.020	0.026	0.089	0.114	0.018	0.026	0.042	0.039	86	81	86	71	82	79

Table 68 - Strobe Current Ratings

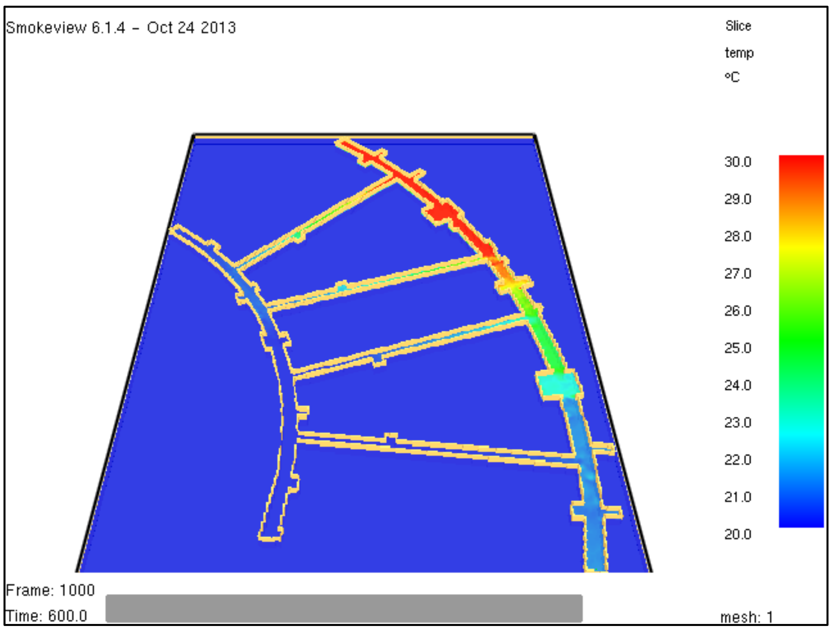
	Table 2: Strobe Current Ratings						
	RMS Current (amps)						
Model	MT-121575	MT-241575	MTWP-2475	MT-24MCW			
Candela	1575cd	1575cd	180cd	15cd	30cd	75cd	110cd
@ 24VDC	0.152	0.060	0.094	0.041	0.063	0.109	0.140
UL max*	0.255	0.090	0.138	0.060	0.092	0.165	0.220

9.13 Appendix M: Scenario 1 FDS Results



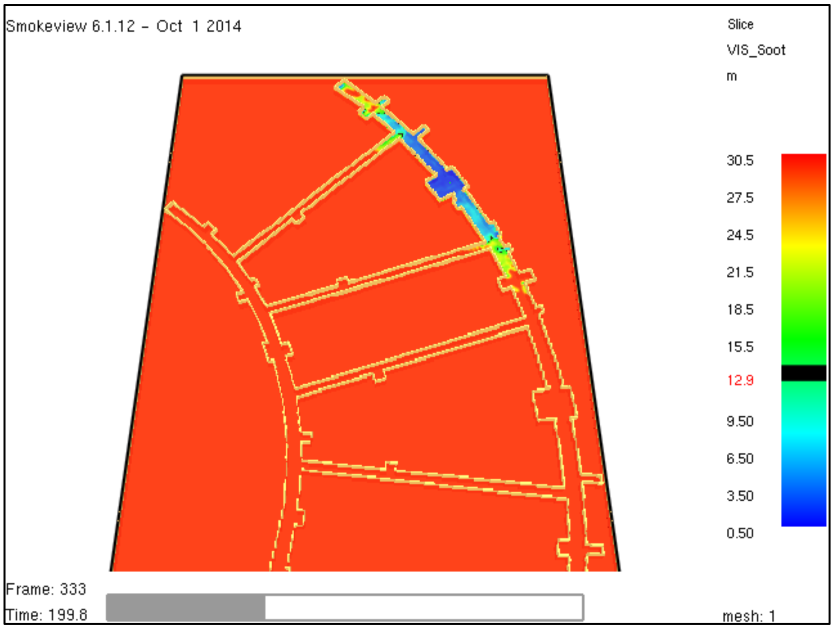
Flashover Criteria: $T_{upper\ layer} = 500\ °C$

Figure 66 - Scenario 1 (Upper Layer Temperature – Flashover)



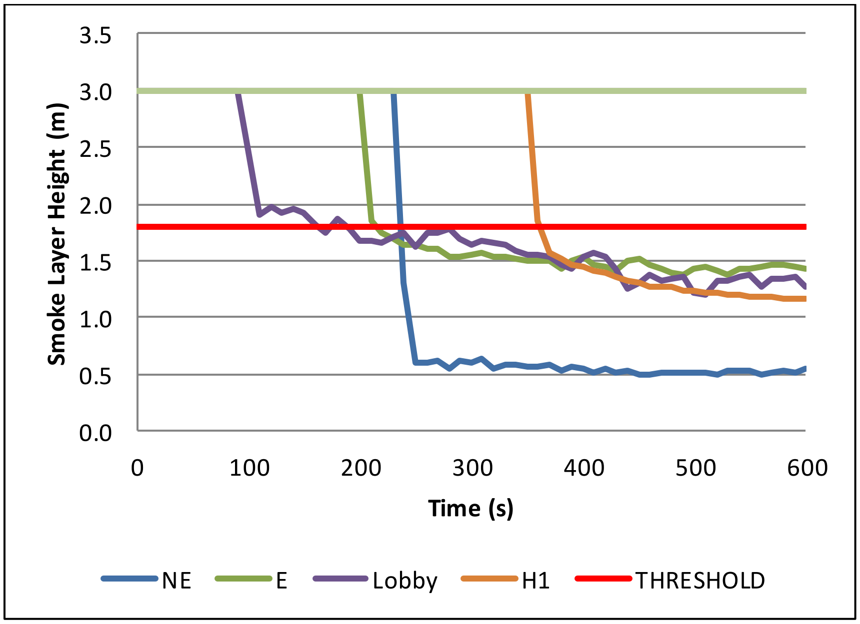
Flashover Criteria: $T = 60\ °C$

Figure 67 - Scenario 1 (Temperature)



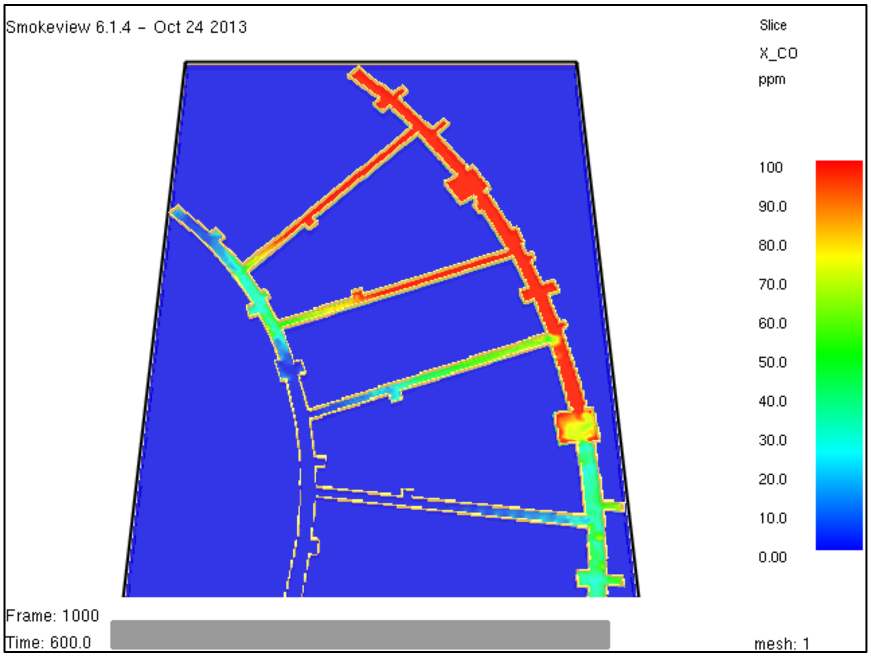
Visibility Criteria = 13 m

Figure 68 - Scenario 1 (Visibility)



Smoke Layer Criteria = 1.8 m

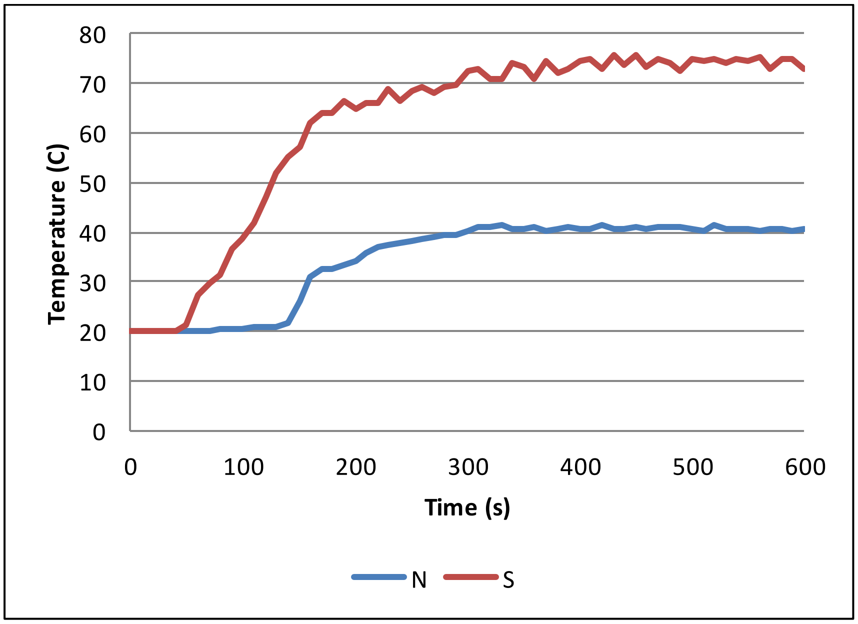
Figure 69 - Scenario 1 (Smoke Layer Height)



Carbon Monoxide Criteria $= 1000$ ppm

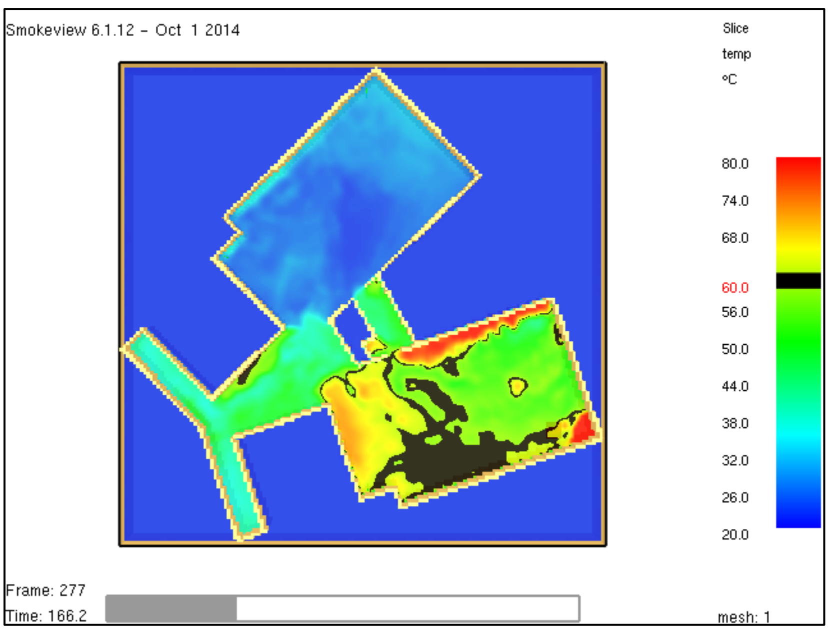
Figure 70 - Scenario 1 (Carbon Monoxide)

9.14 Appendix N: Scenario 2 FDS Results



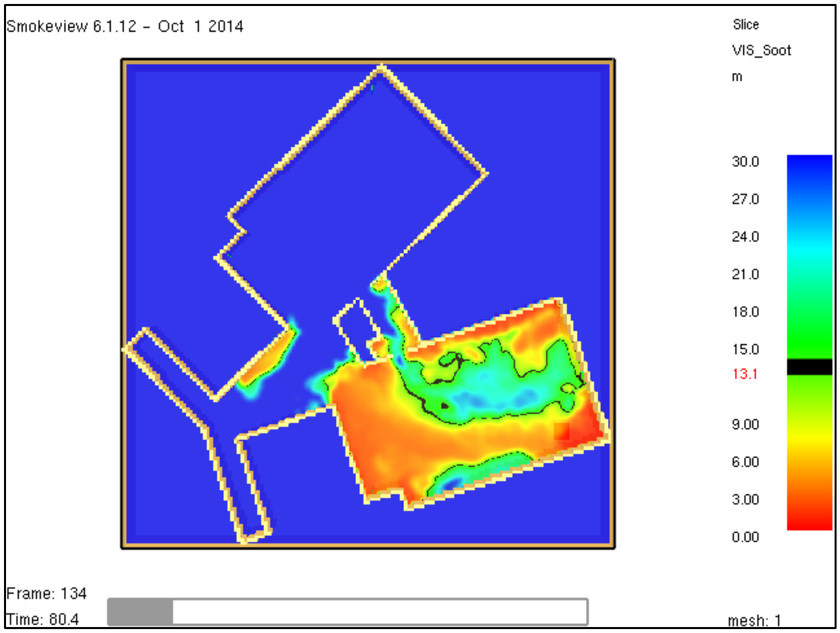
Flashover Criteria: $T_{upper\ layer} = 500\ °C$

Figure 71 - Scenario 2 (Upper Layer Temperature – Flashover)



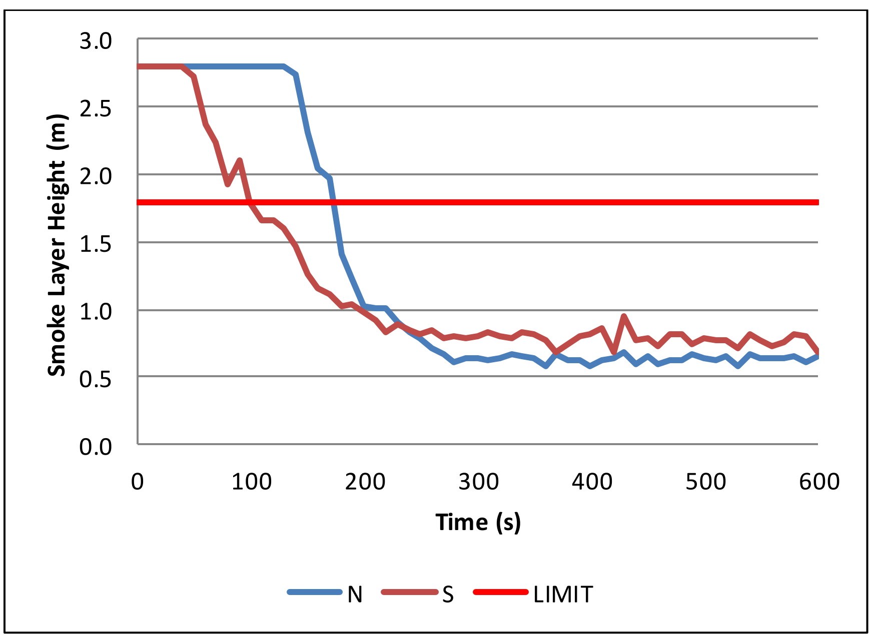
Flashover Criteria: $T = 60\ °C$

Figure 72 - Scenario 2 (Temperature)



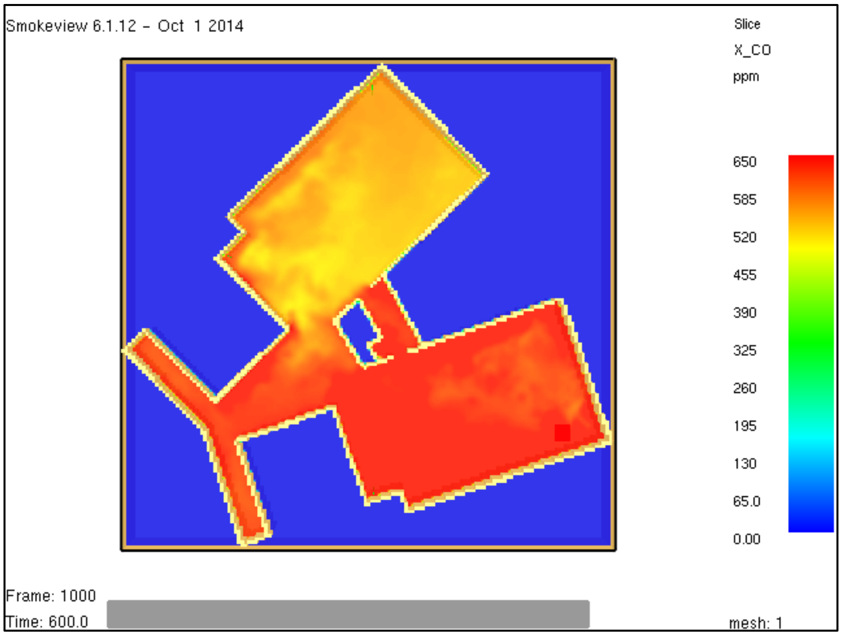
Visibility Criteria $= 13$ m

Figure 73 - Scenario 2 (Visibility)



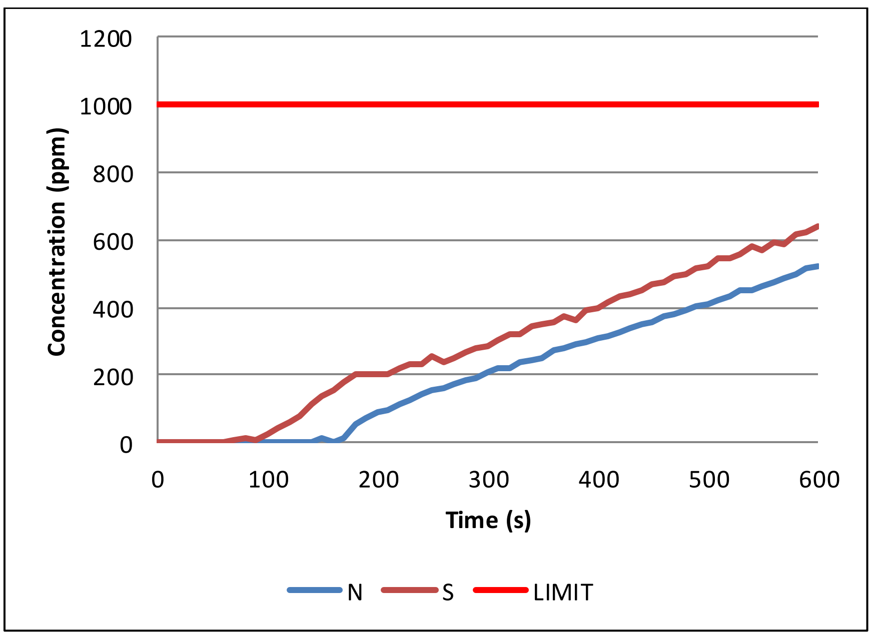
Smoke Layer Criteria $= 1.8$ m

Figure 74 - Scenario 2 (Smoke Layer Height)



Carbon Monoxide Criteria = 1000 ppm

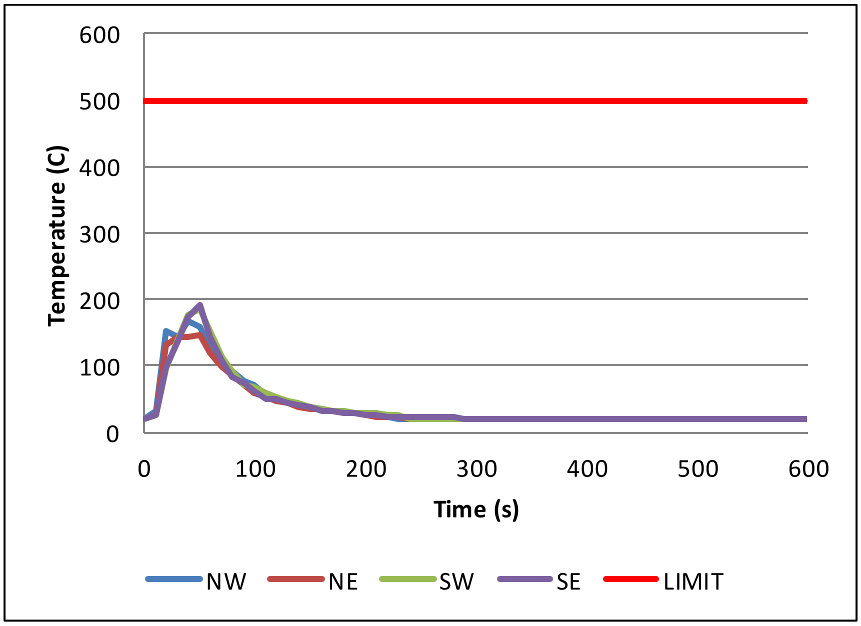
Figure 75 - Scenario 2 (Carbon Monoxide)



Carbon Monoxide Criteria = 1000 ppm

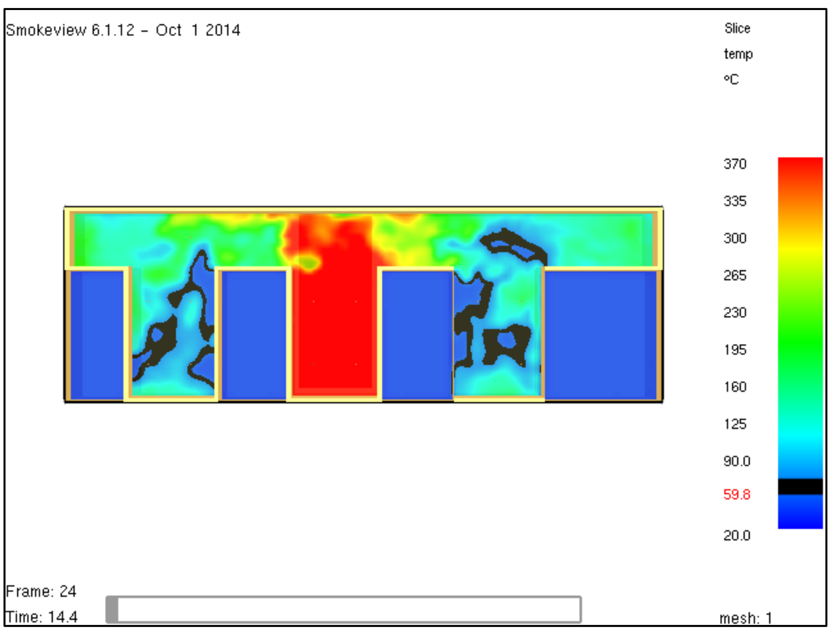
Figure 76 - Scenario 2 (Carbon Monoxide Concentration)

9.15 Appendix O: Scenario 3 FDS Results



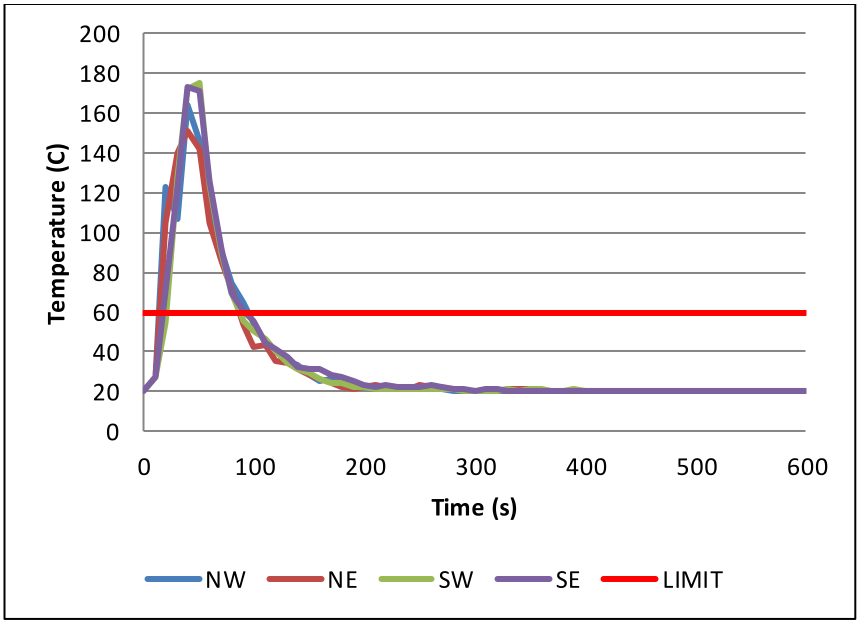
Flashover Criteria: $T_{\text{upper layer}} = 500\ °C$

Figure 77 - Scenario 3 (Upper Layer Temperature – Flashover)



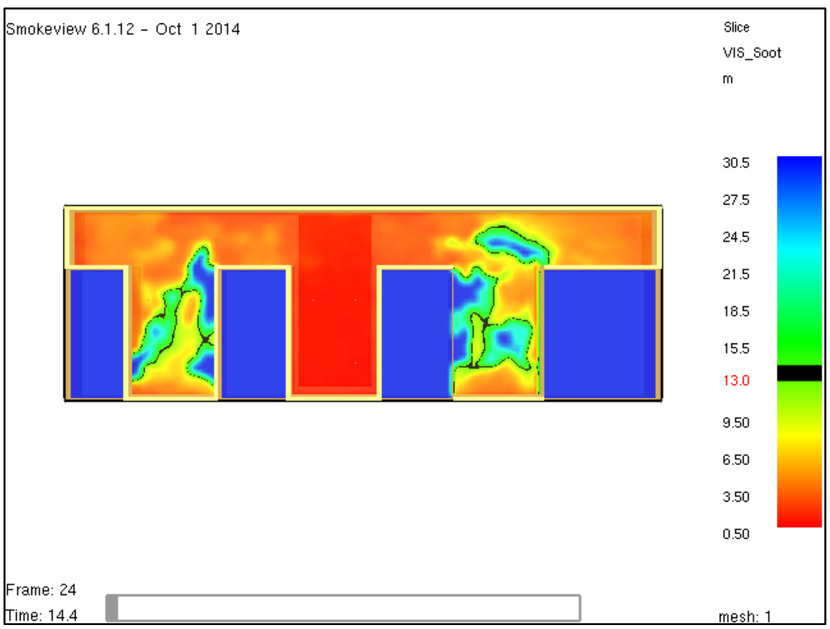
Flashover Criteria: $T = 60\ °C$

Figure 78 - Scenario 3 (Temperature)



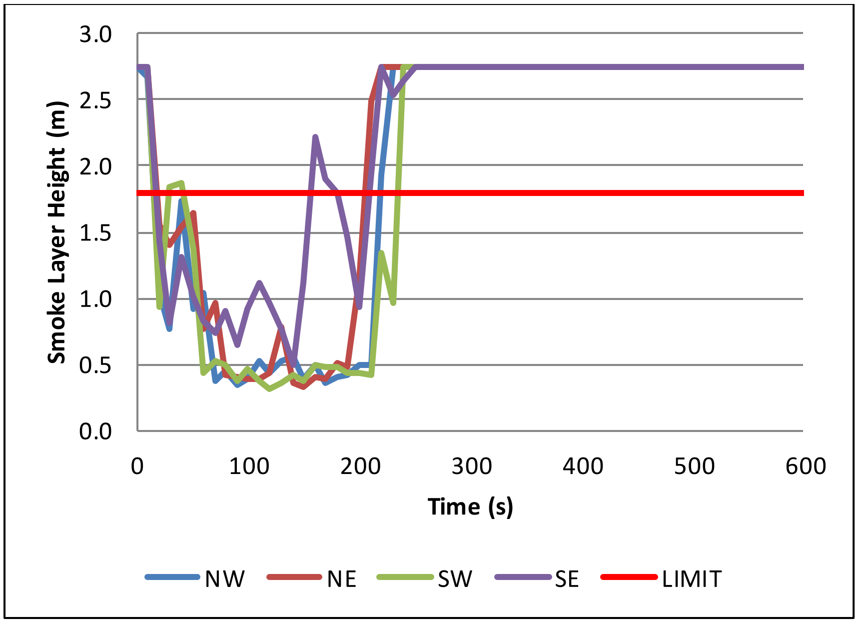
Flashover Criteria: $T = 60\ °C$

Figure 79 - Scenario 3 (Temperature)



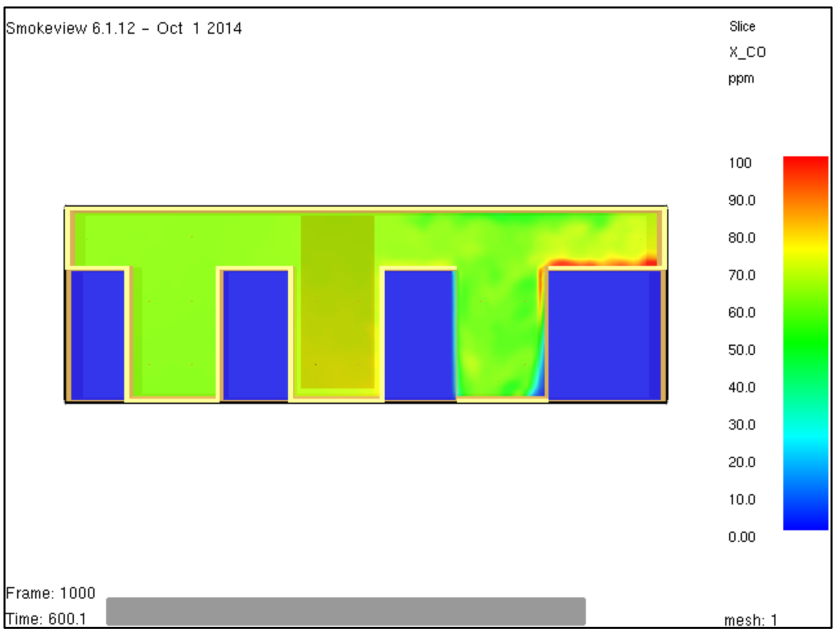
Visibility Criteria $= 13\ m$

Figure 80 - Scenario 3 (Visibility)



Smoke Layer Criteria = 1.8 m

Figure 81 - Scenario 3 (Smoke Layer Height)



Carbon Monoxide Criteria = 1000 ppm

Figure 82 - Scenario 3 (Carbon Monoxide)