Cal Poly State University

Robert E. Kennedy Library

Fire Protection Analysis Report

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Keywords:

Life Safety Code
Fire Protection Analysis
Performance-Based Design
Fire Dynamics Simulator (FDS)

i. Executive Summary

This report determines whether or not the fire protection and life safety features of Robert E. Kennedy Library are consistent with the fire protection objectives established in nationally recognized fire protection codes and standards. This analysis is performed to establish a technical baseline for identification of fire protection deficiencies.

Kennedy Library is the campus student library at California Polytechnic State University. The facility provides resources and services in a variety of media to meet the needs of university students and faculty.

This analysis consists of a prescriptive analysis and a performance-based analysis. The prescriptive analysis is an analysis of the building and its compliance with the building code and other industrial codes and standards. The performance-based analysis is based on guidance from NFPA 101 and evaluates the fire protection features of the building against specific performance criteria.

The prescriptive analysis consists of a review of Kennedy Library's fire protection features against code requirements. The features reviewed include structural fire resistance, automatic alarm and detection, suppression, and life safety. The results of the prescriptive analysis include the identification of two deficiencies, one potential deficiency that should be analyzed further and one recommendation for improving the safety posture of the facility. The deficiencies are (1) inadequate visual notification coverage of the fire alarm system and (2) incorrect door swing direction of two doorways in the means of egress from the building's interior courtyard. The potential deficiency is the coverage provided by the fire alarm system for audible notification. The recommendation is for the installation of an automatic fire sprinkler system.

Whereas adherence to prescriptive codes and standards provides an implicit assurance of safety, a performance-based analysis is performed with explicit safety objectives as the criteria for measuring success. The performance-based analysis evaluates whether the fire protection features in the building will protect the building occupants in the event of a fire. The criteria for acceptability are based on industry accepted tenability thresholds for building occupants. There are many criteria that can be used; the criteria used in this analysis are visibility reduction (13 m and 4 m) and temperature exposure (80ºC for 15 min). During this analysis a fire was modelled inside the library's main entrance. The fire resulted in the main entrance being blocked prior to completion of egress (16 min), which has been determined through the use of hydraulic calculations. The results of the performance-based design indicate that, with the main entrance to Kennedy Library blocked by a large fire, the fire protection features of the building provide sufficient protection for all occupants to be able to escape prior to being exposed to untenable conditions.

The analysis concludes that the intent of nationally recognized fire protection codes and standards is met for Kennedy Library and the fire protection objectives of NFPA 101[8] will be met when the deficiencies identified in this report are resolved.

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1.0 INTRODUCTION

This report documents a fire protection analysis of Robert E. Kennedy Library. Kennedy Library is located on the campus of California Polytechnic State University in San Luis Obispo, California. It is the student library for the university. The building was constructed in 1980. It is a 5-story building, constructed of reinforced concrete. The building is 72 feet tall and 208,000 sq. ft. in area. Figures 1 through 5 each show a layout of one of the building's floors.

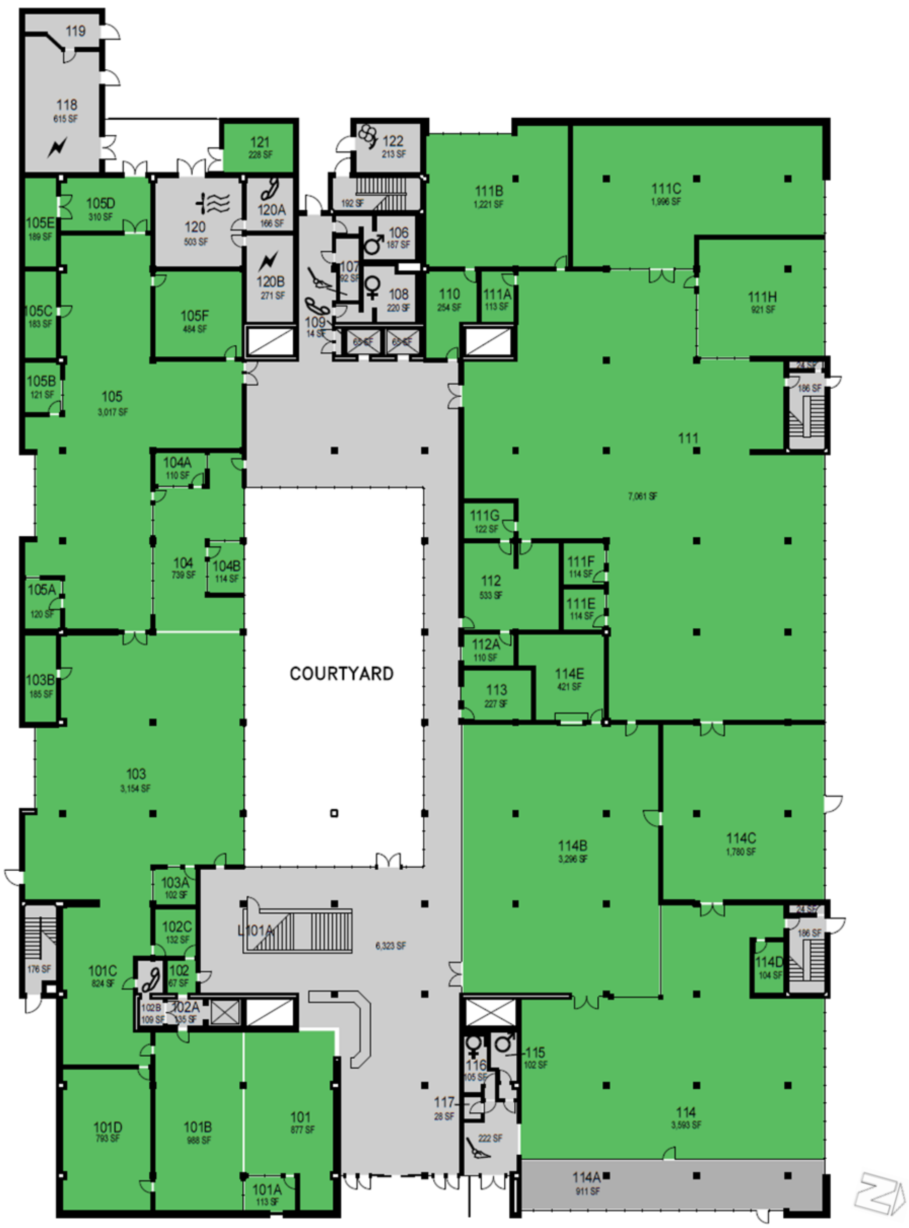


Figure 1- Robert Kennedy Library First Floor Layout

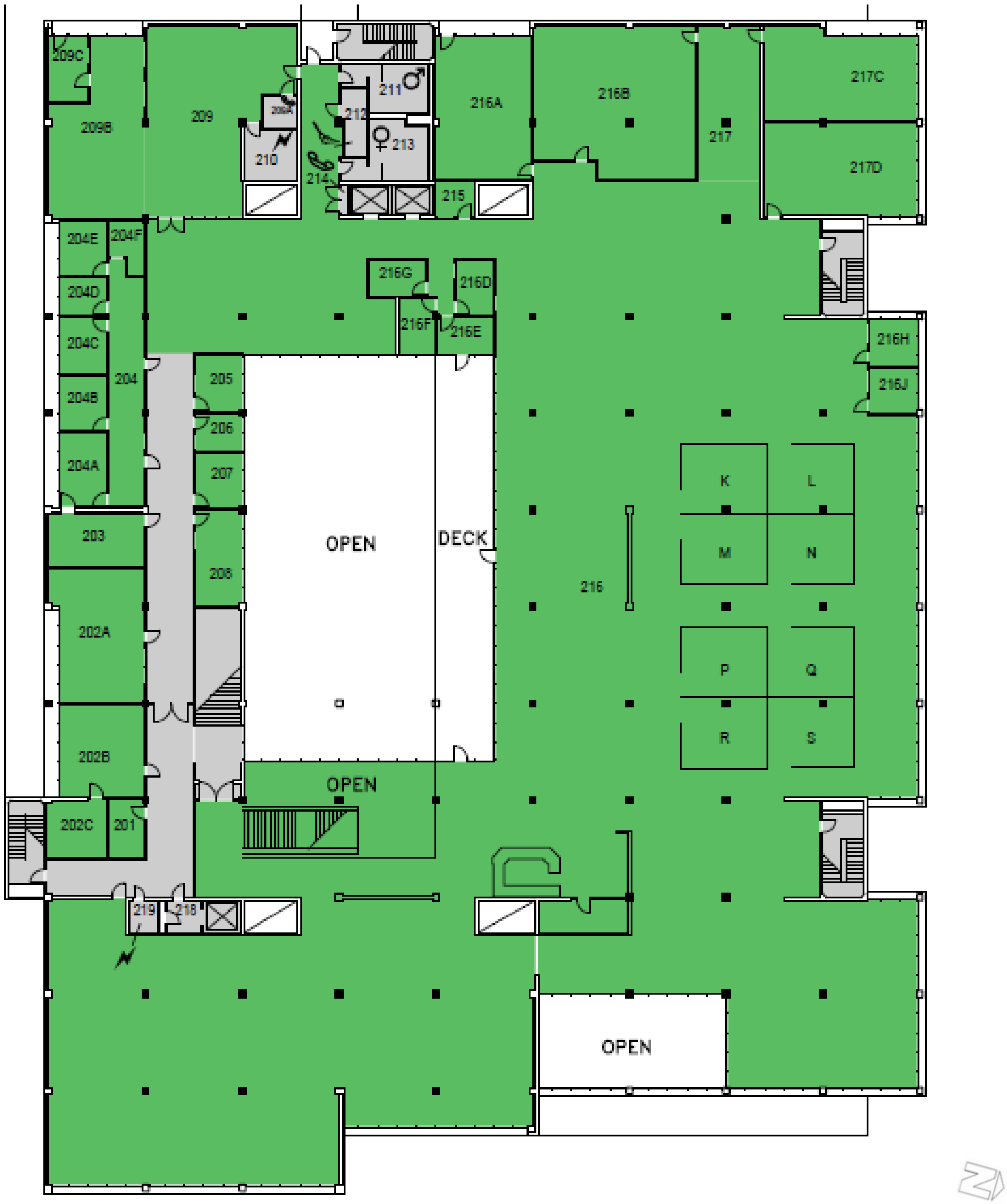


Figure 2- Robert Kennedy Library Second Floor Layout

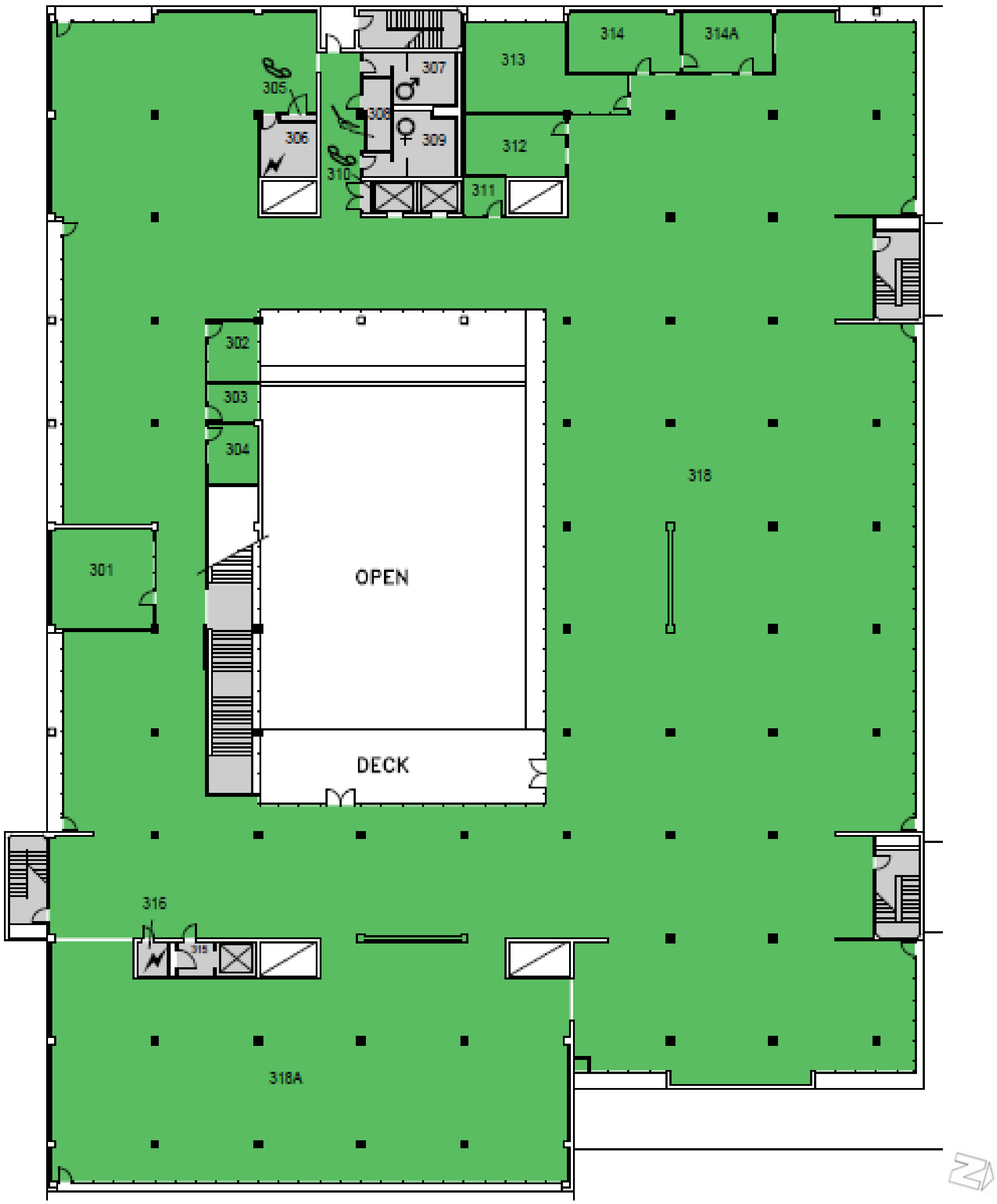


Figure 3- Robert Kennedy Library Third Floor Layout

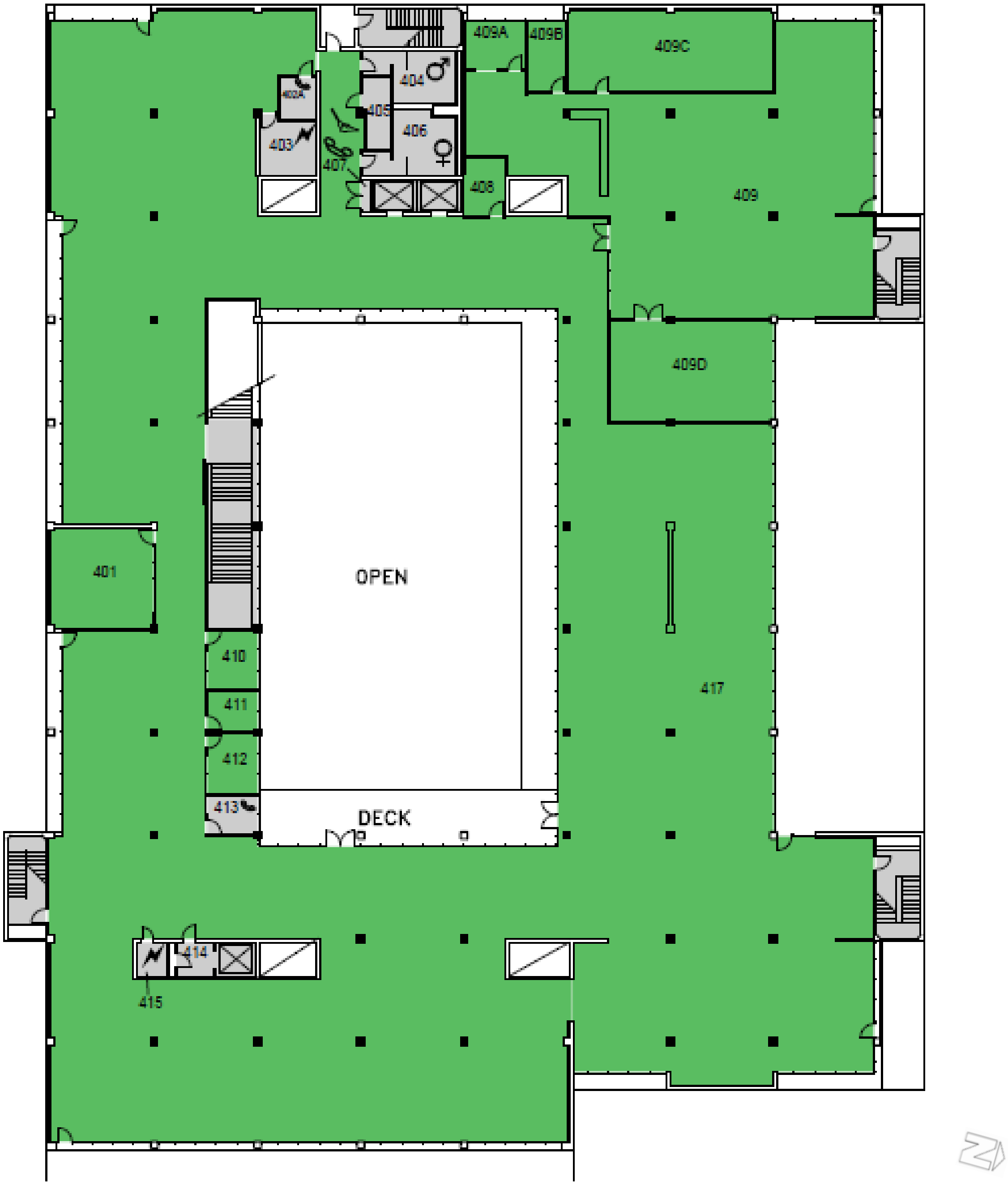


Figure 4- Robert Kennedy Library Fourth Floor Layout

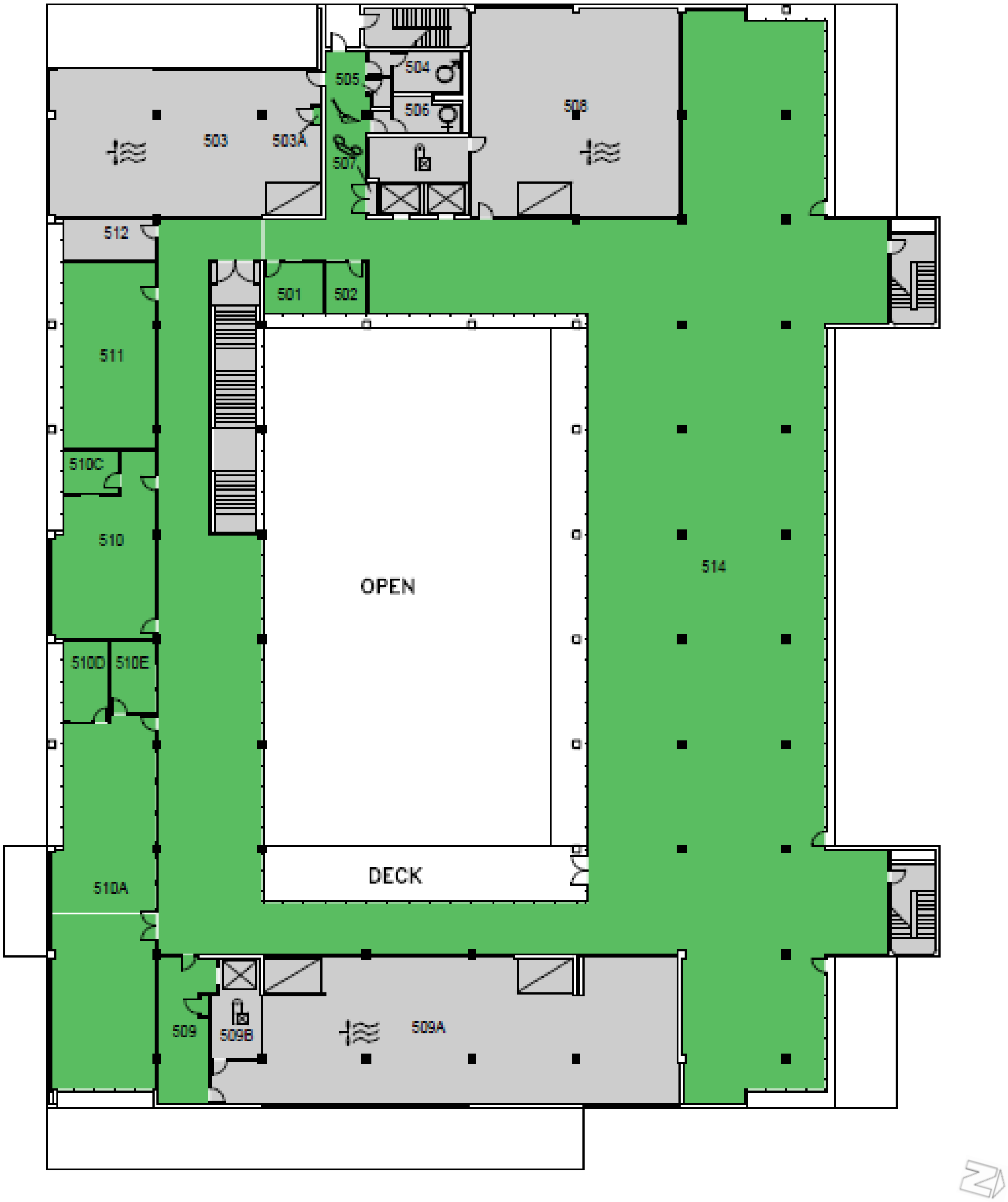


Figure 5- Robert Kennedy Library Fifth Floor Layout

This analysis addresses the facility's compliance with prescriptive requirements from nationally recognized fire protection codes and standards. This analysis also addresses whether the fire protection features and program of the facility are adequate to meet the life safety goals identified in NFPA 101, Life Safety Code(8). The objective of the analysis is to determine whether occupant protection is adequate and to provide recommendations for correcting identified deficiencies and capitalizing recognized opportunities for improvement.

The analysis of the building code and some of the National Fire Protection Association (NFPA) codes are not based on the facility's Code of Record (CoR) but are based on the current editions of the relevant codes. The specific editions of the codes used is identified in Section 6.0 of this report. A large portion of the analysis is based on NFPA 101(8) due to it being applicable to existing facilities.

This document constitutes a fire protection technical baseline for Kennedy Library and should be updated as needed and upon resolution of identified deficiencies and implementation of improvements.

2.0 FACILITY DESCRIPTION

2.1. GENERAL DESCRIPTION AND LOCATION

Robert E. Kennedy Library is located on the campus of California Polytechnic State University in San Luis Obispo, California. It is the student library for the university. The building was constructed in 1980. It is a 5-story building, constructed of reinforced concrete. The building is 72 feet tall and 208,000 sq. ft. in area. The floor levels are 14 feet in height with drop ceilings in many areas which are 9 feet above the finished floor. The building is composed of fire-resistant structural members and is partially sprinklered.

2.2. CONSTRUCTION FEATURES

2.2.1. BUILDING CONSTRUCTION

The primary structural frame consists of reinforced concrete columns and reinforced concrete load bearing walls, floors and roof slab. The roof slab is supported by steel structural members. The non-load bearing walls and partitions are non-combustible, concrete and metal studs.

Kennedy Library is equipped with five stairways. Four of the stairways are located on the perimeter of the building and are completely enclosed. The fifth stairway (stairway #1) is an interior stairway. It is not open on the first and second floor but is enclosed from the third thru the fifth floor.

The four perimeter stairways qualify as exits for each floor level in accordance with Section of NFPA 101[8]. The interior stairway only qualifies as an exit for the fifth-floor level. The first floor is equipped with seven exits. On the second through fourth floors there is access to four of the exit stairways and on the fifth floor there is access to three of the exit stairways.

2.2.2. INTERIOR FINISH

Interior wall and ceiling finish materials are classified in accordance with ASTM E 84[13] or UL 723[15] by the IBC[1] and NFPA 101[8]. Wall and ceiling finishes are classified as follows:

Class A: = Flame spread index 0-25; smoke-developed index 0-450.

Class B: = Flame spread index 26-75; smoke-developed index 0-450.

Class C: = Flame spread index 76-200; smoke-developed index 0-450.

The requirements for interior finish of a building are based on its occupancy classification. According to NFPA 101[8] (Section 13.3.3), general assembly areas with occupant loads greater than 300, corridors, and lobbies of assembly occupancies must be class A or class B ceiling and wall finishes; enclosed stairways must be class A. The IBC[1] has the same requirements for interior finishes in this type of assembly occupancy except that it also requires class A finishes in corridors for buildings that are not equipped with automatic fire sprinkler systems.

Interior floor finishes, based on the IBC(1) and NFPA 101(8), must be classified in accordance with ASTM D 2859(12). Floor finishes are classified as follows:

Class I: = interior floor finish shall have a critical radiant flux of not less than 0.45 W/cm^2

Class II: = interior floor finish shall have a critical radiant flux of not less than 0.22 W/cm^2, but less than 0.45 W/cm^2

According to NFPA 101(8) (Section 13.3.3.5), there are no requirements for floor finishes in existing assembly occupancies. The IBC(1) requires that interior floor finishes in assembly occupancies have a minimum critical radiant flux, not less than that of class II finishes.

2.2.3. FACILITY CLASSIFICATION

2.2.3.1. International Building Code

The requirements for the fire resistance of structural members is based on the proposed building height, number of stories and floor area and these requirements are found in Chapter 5 of the IBC(1). Whether a building is equipped with automatic fire sprinklers and how much access there is from a building to a public way can also have an effect on the minimum type of construction permitted. Table 504.3 (shown in Table 1 of this report) of the IBC(1) identifies the maximum allowable height above grade plane for a building, based on occupancy classification and whether the building is sprinklered.

Table 1- Allowable Building Height in Feet Above Grade Plane

OCCUPANCY CLASSIFICATION	SEE FOOTNOTES	TYPE OF CONSTRUCTION								
		TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
		A	B	A	B	A	B	HT	A	B
A, B, E, F, M, S, U	NS[b]	UL	160	65	55	65	55	65	50	40
	S	UL	180	85	75	85	75	85	70	60
H-1, H-2, H-3, H-5	NS[c, d]	UL	160	65	55	65	55	65	50	40
	S									
H-4	NS[c, d]	UL	160	65	55	65	55	65	50	40
	S	UL	180	85	75	85	75	85	70	60

Kennedy Library has a height of 72 ft above grade, is not sprinklered and is classified as A-3; therefore, the minimum construction type is Type I-B.

Table 504.4 (shown in Table 2 of this report) of the IBC[1] identifies the maximum allowable number of stories above grade plane for a building, based on occupancy classification and whether the building is sprinklered.

Table 2- Allowable Number of Stories Above Grade Plane

OCCUPANCY CLASSIFICATION	SEE FOOTNOTES	TYPE OF CONSTRUCTION								
		TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
		A	B	A	B	A	B	HT	A	B
A-1	NS	UL	5	3	2	3	2	3	2	1
	S	UL	6	4	3	4	3	4	3	2
A-2	NS	UL	11	3	2	3	2	3	2	1
	S	UL	12	4	3	4	3	4	3	2
A-3	NS	UL	11	3	2	3	2	3	2	1
	S	UL	12	4	3	4	3	4	3	2
A-4	NS	UL	11	3	2	3	2	3	2	1
	S	UL	12	4	3	4	3	4	3	2
A-5	NS	UL	UL	UL	UL	UL	UL	UL	UL	UL
	S	UL	UL	UL	UL	UL	UL	UL	UL	UL

Based on the number of stories above grade, not being sprinklered and the occupancy classification, the minimum type of construction for the building is again Type I-B.

Floor area is also a determining factor in the minimum type of construction allowed for a building. Table 506.2 (shown in Table 3 of this report) details the maximum allowable floor area per floor of a building based on its construction type. Kennedy Library floor area exceeds the maximum square-footage for type IIA (non-sprinklered) construction by a significant margin. The area of the library's fifth floor (its smallest floor) is approximately 34,000 sq. ft., meaning that it must at least be considered type IB construction, which is allowed to have unlimited floor area.

Table 3- Allowable Area Factor

OCCUPANCY CLASSIFICATION	SEE FOOTNOTES	TYPE OF CONSTRUCTION								
		TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
		A	B	A	B	A	B	HT	A	B
A-1	NS	UL	UL	15,500	8,500	14,000	8,500	15,000	11,500	5,500
	S1	UL	UL	62,000	34,000	56,000	34,000	60,000	46,000	22,000
	SM	UL	UL	46,500	25,500	42,000	25,500	45,000	34,500	16,500
A-2	NS	UL	UL	15,500	9,500	14,000	9,500	15,000	11,500	6,000
	S1	UL	UL	62,000	38,000	56,000	38,000	60,000	46,000	24,000
	SM	UL	UL	46,500	28,500	42,000	28,500	45,000	34,500	18,000
A-3	NS	UL	UL	15,500	9,500	14,000	9,500	15,000	11,500	6,000
	S1	UL	UL	62,000	38,000	56,000	38,000	60,000	46,000	24,000
	SM	UL	UL	46,500	28,500	42,000	28,500	45,000	34,500	18,000
A-4	NS	UL	UL	15,500	9,500	14,000	9,500	15,000	11,500	6,000
	S1	UL	UL	62,000	38,000	56,000	38,000	60,000	46,000	24,000
	SM	UL	UL	46,500	28,500	42,000	28,500	45,000	34,500	18,000

Based on the classification as I-B, the primary structural frame consisting of reinforced concrete columns, load bearing walls, floors and roof slab are rated for 2-hour fire-resistance. This level of fire resistance is achieved with 18 in. x 18 in. steel reinforced concrete columns and 4 in. thick reinforced concrete floor slabs with 20 in. thick ribs. Fire resistance is a characteristic assigned to construction materials and structural members to provide an indication of how long the material or member is intended to maintain its integrity during exposure to a fire. Fire resistance for a given material is determined through standardized testing. There are several standard furnace tests that are used to determine the fire resistance of a material including the international standard, ISO 834, which is used by many countries. The primary standard which is used and accepted in the United States is the ASTM E 119[14].

A standard furnace test allows you to test materials performance in fire conditions with repeatable results. The material is exposed to specific time-temperature curve that is intended to be more severe than an actual structure fire. The problem with designing a structure's fire protection based on standard testing is that a standardized test, performed in a controlled environment does not consider all factors that can contribute to structural failure.

One of the key factors that is not considered in the ASTM E 119[14] standard test is that of thermal expansion. Under the standard time-temperature curve it is generally assumed that steel will fail around 500°C, however, steel may fail at much lower temperatures when expansion is impeded by other members of the assembly, forcing it to buckle.

2.2.3.2. Fire Exposure Analysis

The IBC[1] details requirements for exterior wall fire resistance levels based on separation distances between buildings, type of construction and occupancy classification. A table is provided in Section 602 of the IBC[1] which can be used to determine the required fire resistance rating. Kennedy Library is greater than 30 feet from adjacent buildings, therefore, fire rated exterior walls are not required. The table is shown below as Table 4.

Table 4- Fire Resistance Requirements for Exterior Walls Based on Fire Separation

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

2.2.3.3. NFPA 101

Table 7.3.1.2 in NFPA 101[8] lists library stack areas and library reading rooms under Assembly Use. Kennedy Library is therefore considered an Assembly Occupancy. Assembly Occupancy is defined in NFPA 101[8] as "An occupancy used for a gathering of

50 or more persons for deliberation, worship, entertainment, eating, drinking, amusement, awaiting transportation, or similar uses." Kennedy Library also has incidental uses for business, storage and mechanical/electrical rooms. Because the secondary uses are incidental, separation of occupancies is not required.

See Attachment 1 for building floor layouts showing occupancy uses of Kennedy Library.

2.3. FACILITY OPERATIONS AND PROCESSES

2.3.1. MISSION AND ASSOCIATED HAZARDS

Whether a fire protection analysis is prescriptive or performance-based, the facility processes and hazards must be understood in order for an appropriate level of protection to be provided. Kennedy Library is a storage facility; however, it differs from other storage facilities in that it is subject to a high level of activity.

The hazards present in the library are limited. The primary fire hazard is the large amount of ordinary combustibles in the form of historical and reference documents. Kennedy Library houses over 600,000 printed books along with many other records which are retained in other formats. As a facility that stores primarily combustible materials, the fire load is a major consideration.

2.3.2. FUEL ANALYSIS

The fuel load of the building is primarily paper products and furniture consisting of metal. wood, fabrics and foams. The most important characteristic of a fuel is the Heat Release Rate (HRR). Once the HRR for a fuel has been determined through fire testing, a reasonable estimation of how the fuel will burn in a fire can be made. Because HRR data is so vital, extensive fire testing has been performed on materials and objects to gather this much-needed data. It is not possible to determine the flammability characteristics of an object based on the flammability characteristics of the object's components; therefore, research must be done to determine how an object's made up of different materials will burn. The empirical data derived from this research is one of the primary tools utilized when postulating how a fire will evolve in a space.

The NFPA Fire Protection Handbook[(10)] contains information on characteristic fire loads, for certain occupancy uses, which was collected in surveys of buildings. Tables 18.1.2 and 18.1.6 of the NFPA Fire Protection Handbook[(10)] provide characteristic fuel load values for libraries. The data provided in both tables indicates that libraries have an average fuel load of approximately 2500 MJ/m^2.

Kennedy Library is a robust concrete structure with a high level of fire resistance. The building has a heavy fire load but the hazard presented by the fuel packages is not severe as the material is mostly ordinary combustible. The information contained in this facility description sets the stage for what type of active fire protection features might be necessary to protect the building structure and occupants.

3.0 PRESCRIPTIVE ANALYSIS

3.1. FIRE PROTECTION FEATURES

3.1.1. FIRE DETECTION AND ALARM SYSTEMS

Kennedy Library is with a conventional, manually initiated, fire alarm system. The fire alarm control panel (FACP) is a Simplex, model 4120. NFPA 101[8] requires a fire alarm system for existing assembly occupancies. If Kennedy Library were to be built today, it would be required per the IBC[1] to be protected by an automatic fire alarm and detection system.

The fire alarm system in Kennedy Library does provide partial automatic detection but the automatic capabilities are designed primarily to support building control functions. The purpose of control functions in the fire alarm system are to provide specific emergency control or supervisory functions in the event of a fire that improve the building occupant’s level of protection. The control functions provided in Kennedy Library are occupant notification, HVAC system shutdown, elevator recall, sprinkler supervision, and door release.

3.1.1.1. International Building Code

The IBC[1] requires that Group A occupancies, with an occupant load of 300 or more, be equipped with a fire alarm system that can manually initiate occupant notification (Section 907.2.1). The IBC[1] also requires that activation of the fire alarm system in Group A occupancies with an occupant load of 1,000 or more shall initiate an emergency voice/alarm communications system (EVACS) (Section 907.2.1.1). The requirement of section 907.2.1 for a manually initiated fire alarm system is met, however there is no EVACS installed in the library. An EVACS was likely not required at the time of the library’s design and construction.

The IBC[1] also requires that an automatic sprinkler system be provided throughout Kennedy Library (Section 903.2.1). There does exist partial automatic sprinkler protection in the building and it is supervised by a waterflow switch, allowing it to function as another form of automatic detection (NFPA 13[3], Section 7.3.2.4). The protection provided is not throughout Kennedy Library, and, therefore, fails to meet the requirement in Section 903.2.1 of the IBC[1].

3.1.1.2. NFPA 101

A fire alarm system is required to be installed in Kennedy Library, per NFPA 101[8], based on the occupancy classification and the occupant load. The fire alarm system must be approved in accordance with, Sections 9.6.1 and 13.3.4 of NFPA 101[8]. It is stated in Section 13.3.4.1.1 that a fire alarm must be provided in assembly occupancies with occupant loads of more than 300. Per Section 13.3.4.2.1 of NFPA 101[8], the system in Kennedy Library is required to be initiated by both:

1. Manual means in accordance with Section 9.6.2.1(1) of NFPA 101[8]
2. Sprinkler system waterflow supervision where automatic sprinklers are provided.

The fire alarm system in Kennedy library was designed to be initiated through manual means and sprinkler system supervision. The manual fire alarm boxes meet the requirements for existing alarm system installations of Section 9.6.2.3(2) which states that the alarm boxes must be installed in the natural exit access path near each required exit. Kennedy Library is not required to be equipped with automatic fire suppression under the requirements of NFPA 101[8], it is however, provided with a partial coverage sprinkler system which is equipped with waterflow detection.

3.1.1.3. Design Criteria

The design criteria for automatic fire alarm and detection systems are found primarily in NFPA 72[6]. NFPA 72 provides design and installation requirements for fire alarm panels, circuits and pathways, initiation devices, notification appliances, system power, inspection, testing, maintenance, emergency communications and supervising stations.

The riser diagram and signaling plans can be found in Attachment 2.

3.1.1.4. Alarm Initiation

The fire alarm system installed in Kennedy Library is equipped with spot-type photoelectric smoke detectors (including duct detectors), a waterflow switch and manual fire alarm boxes. The primary function of the smoke detectors in this system is to control other emergency control functions.

Sprinkler systems are required to be automatically supervised per Section 7.3.2.4 of NFPA 13[3]. The waterflow switch that is installed in the partial coverage automatic sprinkler system will, upon detecting flow, send a signal to the FACP that will initiate an alarm. Activation of the initiating device shall occur within 90 seconds of waterflow at the alarm-initiating device when flow occurs that is equal to or great than that from a single sprinkler of the smallest orifice size installed in the system (Section 17.12.2, NFPA 72[6]). The waterflow switch is installed on the system side of the building riser.

The Kennedy Library fire alarm system is equipped with 29 manual fire alarm boxes. The manual fire alarm boxes are provided at every exit in accordance with the fire alarm initiating requirements of NFPA 101[8], Section 9.6.

3.1.1.5. Alarm Notification

The Kennedy Library fire alarm system is equipped with 31 audio/visual (A/V) notification appliances. A combination horn/strobe must meet the installation requirements of visual devices from NFPA 72[6] (Section 18.4.8.3). Wall-mounted, combination horn/strobes must be installed so that the entire lens is not less than 80 in. and not greater than 96 in. above the finished floor (AFF).

Audible notification appliances must be selected and located such that the required sound pressure level (SPL) is met in all areas that are required to be served by the system. Audible public mode signals shall have a SPL of at least 15 dBA above the average ambient sound level or 5 dB above the maximum sound level having a duration of at least 60 seconds, whichever is greater (Section 18.4.3). The total SPL of a space (ambient + introduced) must not exceed 110 dBA at the minimum hearing distance. Based on a review of the system layout drawings, the audible notification coverage appears to be sparse. There is a rule of thumb that sound pressure level emanating from a notification device will drop by 6 dB for each time that the distance from the device is doubled. Using this rule of thumb, the sound pressure level at any point in a building can be estimated based on the distance from nearby notification appliances. A sound level survey should be performed to determine whether the audible notification coverage is adequate in accordance with NFPA 72(6).

The average ambient sound pressure level of different occupancies can be found in Table A.18.4.3 of NFPA 72(6) and is shown in Table 5. Based on Table 5, the average ambient sound level in Kennedy Library can be expected to be 55 dBA based on the locations of business and places of assembly. Therefore, the minimum sound pressure level emanating from the notification appliances is required to be 70 dBA at any point within the building.

Table 5- Average Ambient Sound Level According to Location

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

The IBC(1) requires that visual notification coverage be provided throughout all shared space. This requirement is not met; however, the IBC(1) is not the building's CoR, therefore this is not a deficiency. NFPA 101(8) requires that visual notification coverage be provided in all areas which could serve occupants that are hearing impaired. All public areas of Kennedy Library can be assumed to serve hearing impaired occupants. As the visual notification coverage is sparse, Kennedy Library is likely not in compliance with this requirement and it is therefore a deficient condition.

3.1.1.6. Control Function

The purpose of the smoke detectors installed in Kennedy Library is to activate emergency functions that enhance fire protection and life safety; these functions include elevator recall, door operation and shutdown of the air distribution system.

Elevator recall serves two purposes: firstly, the elevators are taken control of which prevents building occupants from being delivered to the fire area, secondly it secures operation of the elevators for fire service use. In multi-story buildings, elevators are often used by the fire department to gain quick access to the vicinity of the fire.

The doors serving stairwell #1 are held open with automatic door closers. Door release is a common control function of fire alarm systems, particularly in institutional occupancies. The purpose of door release is to allow for the propping open of fire doors in fire/smoke barriers for day-to-day convenience while being able to depend on the doors providing separation in the event of an emergency. Where door release is accomplished through smoke detector activation, the detector shall be listed for releasing service (Section 17.7.5.6, NFPA 72(6)).

3.1.1.7. NFPA 90A

Some components of the Kennedy Library fire alarm system are required per NFPA 90A(7). It is stated in Section 6.4.2.1(1) of NFPA 90A(7) that smoke detectors listed for use in air distribution systems shall be located downstream of the air filters and ahead of any branch connections in air supply systems having a capacity greater than 2,000 cubic feet per minute (CFM).

Air distribution system shutdown is a critical operation performed by fire protection systems in large, multi-story buildings. The mechanical dispersal of combustion products throughout a space could cause delay in the detection and suppression of a fire. Duct detectors are not required to initiate an alarm per Section 17.7.4.4 of NFPA 72(6), therefore, if they activate and do not shutdown the air distribution system, their supervisory signal could easily be ignored and result in the spread of smoke to other areas of the building.

Kennedy library has twenty-five air handling units (AHUs) installed in mechanical rooms on the 5th floor. All twenty-five of these AHUs have capacities exceeding 2,000 CFM, and all are equipped with duct smoke detectors.

3.1.1.8. Power Supply

Fire alarm systems (FAS) are required to be configured with two independent and reliable power supplies, a primary and a secondary (Section 10.6.3.2, NFPA 72(6)). A FAS may be configured with a single power supply if it is an Uninterruptible Power Supply (UPS) in accordance with Section 10.6.4 of NFPA 72(6). All primary and secondary power supplies shall be monitored for voltage at the point of connection to the system. Failure of a power supply shall result in a trouble signal (Section 10.6.9.1.1).

The primary power supply is required to be fed by a dedicated branch circuit. The primary power supply may originate from one of the following sources:

1. Electric utility
2. An engine-driven generator or equivalent in accordance with 10.6.11.2, where a person trained in its operation is on duty at all times
3. An engine-driven generator or equivalent arranged for cogeneration with an electric utility in accordance with 10.6.11.2, where a person trained in its operation is on duty at all times

Operation of a system on a secondary power supply shall not affect the required performance of the system. The secondary power supply shall have sufficient capacity to operate the system under quiescent load for a minimum of 24 hours and, at the end of that period, shall be capable of operating all alarm notification appliances used for evacuation or to direct aid to the location of the emergency for 5 minutes. A system designed for emergency voice/alarm communication service shall be configured with a secondary power supply with sufficient capacity for 24 hours under quiescent load plus 15 minutes in full alarm (Section 10.6.7.2, NFPA 72(6)).

Secondary power supply for protected premises fire alarm systems shall consist of either storage batteries dedicated to the system or an automatic-starting, engine-driven generator provided with 4 hour capacity batteries (Section 10.6.7.3, NFPA 72(6)).

The building's FACP is a Simplex, Model 4120. The device models could not be determined; device data sheets from Simplex 4120 compatible devices were used to calculate the needed battery capacity for the secondary power supply. Table 6 shows the battery calculation for Kennedy Library fire alarm system:

Table 6- FACP Battery Calculation

Component	Qty	Supervisory Current (AMPS)		Alarm Current (AMPS)	
		Unit	Total	Unit	Total
FACP	1	0.12	0.12	1.5	1.5
Smoke Det.	27	0.0004	0.01	0.0004	0.01
Duct Det.	25	0.0004	0.01	0.0004	0.01
Horn/Strobe	31	0	0	0.106	3.286
		Total System Standby Current (AMPS)	0.14	Total System Alarm Current (AMPS)	4.806

Required Standby Time (hrs.)		Total System Standby Current (AMPS)		Required Standby Capacity (AMP/hrs.)		Required Alarm Time (hrs.)		Total System Alarm Current (AMPS)		Required Alarm Capacity (AMP/hrs.)
24	x	0.14	=	3.36		0.0833	x	4.806	=	0.4

Required Standby Capacity (AMP/hrs.)		Required Alarm Capacity (AMP/hrs.)		Total Required Capacity (AMP/hrs.)		Safety Factor		Required Battery Capacity (AMP/hrs.)
3.36	+	0.4	=	3.76	x	1.2	=	4.512

With the possible exception of the notification appliance coverage, the Kennedy Library FAS meets the prescriptive requirements on NFPA 72. The FAS plays a significant part in the performance-based analysis of Kennedy Library as it is the initiator of the occupant evacuation. The following section discusses the lack of automatic fire suppression. Due to the fact that Kennedy Library is not equipped with automatic suppression throughout, the FAS is the only automatic fire protection system installed in the building.

3.1.2. AUTOMATIC FIRE SUPPRESSION SYSTEMS

Kennedy Library is a partially sprinklered building. For the purposes of this analysis, a full coverage sprinkler system was designed and calculated for the 5th floor level of the building.

The requirements for whether a building needs to have an automatic sprinkler installed in it are found in the applicable version of the IBC(1). Section 903.2.1.3 of the IBC(1) states that "An automatic sprinkler system shall be provided for fire areas containing group A-3 occupancies", a requirement which every floor of Kennedy Library falls under. The IBC(1) defers to NFPA 13(3) for the automatic sprinkler system design and installation requirements (Section 903.3.1.1).

3.1.2.1. Hazard Classification

The occupancy hazard classification is the first criteria to be determined. The hazard classifications provided in NFPA 13(3) are based on an assumed fire load according to the type of facility, and what type of sprinkler coverage is needed to suppress a fire in that facility. The hazard classification for the assembly and business areas of the library is Light Hazard (LH). Libraries are mentioned as an example of a light hazard occupancy in Section A.5.2 of Appendix A in NFPA 13(3). Section A.5.2 makes the following distinction between types of article storage in libraries:

"Note that it is not the committee's intent to automatically equate library bookshelves with ordinary hazard occupancies or with library stacks. Typical library bookshelves of approximately 8 ft (2.4 m) in height, containing books stored vertically on end, held in place in close association with each other, with aisles wider than 30 in. (750 mm) can be considered to be light hazard occupancies. Similarly, library stack areas, which are more akin to shelf storage or record storage, as defined in NFPA 232, should be considered to be ordinary hazard occupancies."

The library stacks in Kennedy Library fall within the above criteria.

The mechanical rooms in the building have a different hazard classification than the assembly area and therefore have different design criteria. Section A.5.3.1 in Appendix A of NFPA 13 identifies mechanical rooms as an example of Ordinary Hazard 1 (OH1).

3.1.2.2. Density/Area Criteria

The density/area calculation design method is the most common method that is used. This method gives a design area and a minimum water spray density based on the hazard classification (see Figure 6). This criterion provides a theoretical system demand (multiply the design area times the density) and gives the designer the required flow from each sprinkler which allows the actual demand to be calculated.

The design area and density for the two hazard classifications is as follows:

LH: 1500 sq. ft., 0.10 gpm/sq. ft.
OH1: 1500 sq. ft., 0.15 gpm/sq. ft.

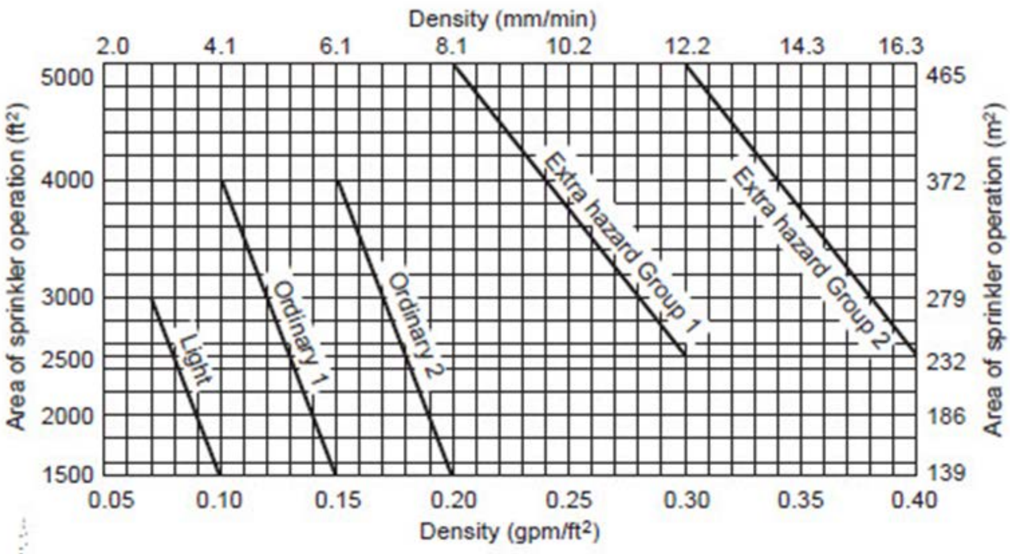


Figure 6- Density/Area Curves

The automatic sprinkler system for Kennedy Library was designed with quick-response (QR) sprinklers. QR sprinklers have a quicker response time than standard response sprinklers and will therefore begin to suppress a fire at an earlier stage. QR sprinklers are required to be used on all new LH systems (unless ESFR sprinklers are being installed) by NFPA 13[(3)] (Section 8.3.3.1). QR sprinklers can also be used in systems that protect OH occupancies.

When QR sprinklers are used in the design of a system for LH and OH occupancies the design area may be reduced where the ceiling height is 20 ft or less (Section 11.2.3.2.3). The graph and equation from NFPA 13[(3)] for calculating the permitted design area reduction are provided in Figure 7.

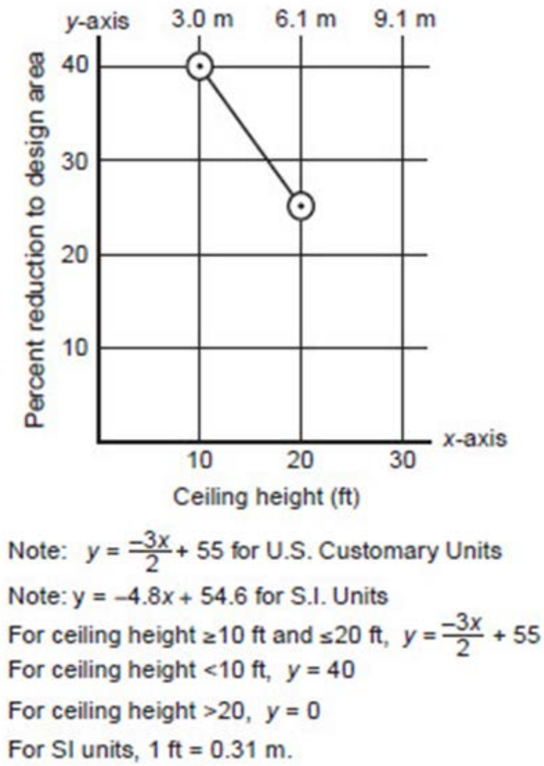


Figure 7- Design Area Reduction for Quick-Response Sprinklers

The permitted reduction in design area for the areas with 9 ft ceilings is 40%. The new design area for the LH occupancy is 900 sq. ft. The allowed reduction in design area for the areas with 13.5 ft ceilings is 34.75%. The new design area for the OH1 occupancy is 979 sq. ft.

3.1.2.3. Coverage Area Per Sprinkler

A sprinklers spray pattern can only cover a limited area. NFPA 13(3) gives a maximum head coverage area based on the design method and the hazard category. The maximum protection area per head for LH in noncombustible construction is 225 sq. ft. (see Table 8.6.2.2.1(a) in NFPA 13(3)). The maximum protection area per head for OH in all construction types is 130 sq. ft. (see Table 8.6.2.2.1(b) in NFPA 13(3)).

3.1.2.4. Sprinkler Layout

The sprinklers must be lain out so that all areas are completely covered by the head's spray patterns. There are a few requirements to take into consideration when deciding the layout.

Firstly, NFPA gives maximum and minimum sprinkler separation distances. The maximum separation distances, between sprinklers, applicable to Kennedy Library for LH and OH1 are both 15 ft (see 8.6.2.2.1 Tables in NFPA 13(3)). The minimum separation between sprinklers is 6 ft unless there is a baffle, conforming to Section 8.6.3.4.2 of the code, installed between the sprinklers.

Secondly, NFPA gives maximum and minimum distances between sprinklers and walls. The maximum distance a sprinkler can be from a wall is one-half the maximum allowable distance between sprinklers (Section 8.5.3.2.1). The minimum distance a sprinkler can be from a wall is 4 in. (Section 8.6.3.3).

Sprinklers may be configured to cover the single head maximum coverage area with any dimensions that fall within the above requirements and don't extend beyond the sprinklers maximum throw distance.

The coverage area used in the design of the LH area is 15ft x 15ft= 225 sq. ft.

The coverage area used in the design of the OH1 area is 11ft-3in x 11ft-3in= 126.5 sq. ft.

Sprinkler and system piping layout drawings can be found in Attachment 3.

3.1.2.5. System Components

The automatic sprinkler system in Kennedy Library will be fitted with 2 types of sprinklers, QR pendent sprinklers with a K-factor of 5.6 for the spaces with drop ceilings, and QR upright sprinklers with a K-factor of 5.6 for the spaces with exposed ceilings.

The main riser will be fitted with a 4 in. isolation valve (OS&Y), a 4 in. check valve with trim package, a 2 in. main drain, gauges, and a waterflow indicator.

Each floor will be a zone, protected by its own system fed by the riser. Each system will consist of a control valve (butterfly), a check valve, a drain, and a waterflow indicator.

3.1.2.6. Hydraulic Calculation

The hydraulic calculations were performed manually using the Hazen-Williams equation. The design area was determined to be in room 509A (mechanical room) on the east end of the 5th floor. Room 509A is the space furthest from the riser and the highest occupancy hazard class (OH1) on the 5th floor. Table 7 shows the calculation. Figure 8 shows the nodes of the design area.

Table 7- Sprinkler System Hydraulic Demand Calculation

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	D= 0.15 gpm/sf K= 5.6 Notes
FPE 523: Kennedy Library Automatic Sprinkler System Hydraulic Calc- Tim Anderson													Date:	3/23/2017
		q	18.9	1"		L	11.25	C=	120	Pt	11.4	Pt		q= 126x.15= 18.9
1	BL-1L			1.049		F				Pe		Pv		Pt=(18.9/5.6)^2
		Q	18.9			T		pf	0.117	Pf	1.3	Pn		
		q	20.0	1 1/4"	T-6	L	7.5	C=		Pt	12.7	Pt		q= 5.6(12.7)^1/2
2	BL-1L			1.38		F	6			Pe		Pv		
		Q	38.9			T	13.5	pf	0.117	Pf	1.6	Pn		
		q				L		C=		Pt	14.3	Pt		BL-1L K=
						F				Pe		Pv		38.9/(14.3)^1/2 =
		Q				T		pf		Pf		Pn		10.29
		q	18.9	1 1/4"	T-6	L	2	C=		Pt	11.4	Pt		q= 126x.15= 18.9
3	BL-1R			1.38		F	6			Pe		Pv		Pt=(18.9/5.6)^2
		Q	18.9			T	8	pf	0.031	Pf	0.2	Pn		
		q				L		C=		Pt	11.6	Pt		BL-1R K=
						F				Pe		Pv		18.9/(11.6)^1/2 =
		Q				T		pf		Pf		Pn		5.55
	BL-1R	q	21.0			L		C=		Pt	11.6	Pt		q(BL-1R)=
4	actual					F				Pe		Pv		5.55(14.3)^1/2
		Q				T		pf		Pf		Pn		
		q		1 1/4"	T-6	L	1	C=		Pt	14.3	Pt		
5	Down RN			1.38		F	6			Pe	0.4	Pv		Pe= 1x.433
		Q	59.9			T	7	pf	0.260	Pf	1.8	Pn		
		q				L		C=		Pt	16.5	Pt		BL-1 K=
						F				Pe		Pv		59.9/(16.5)^1/2 =
		Q	59.9			T		pf		Pf		Pn		14.75
	CM TO	q		1 1/2"		L	11.33	C=		Pt	16.5	Pt		
6	BL-2			1.61		F				Pe		Pv		
		Q	59.9			T		pf	0.123	Pf	1.4	Pn		
	BL-2 TO	q	62.4	2"		L	10.83	C=		Pt	17.9	Pt		q= 14.75(17.9)^1/2
7	BL-3			2.067		F				Pe		Pv		
		Q	122.3			T		pf	0.143	Pf	1.5	Pn		
										Pt	19.4			
	BI-3L	q	18.9	1 1/4"	T-6	L	7.5	C=		Pt	11.4	Pt		BL-3L K=
8				1.38		F	6			Pe		Pv		18.9/(11.8)^1/2 =
		Q	18.9			T	13.5	pf	0.031	Pf	0.4	Pn		5.5
	BI-3R	q	18.9	1 1/4"	T-6	L	2	C=		Pt	11.4	Pt		BL-3R K=
				1.38		F	6			Pe		Pv		18.9/(11.6)^1/2 =
		Q	18.9			T	8	pf	0.031	Pf	0.2	Pn		5.55
	BI-3R	q	19.1			L		C=		Pt		Pt		q(BL-3R)=
9	actual					F				Pe		Pv		5.55(11.8)^1/2
		Q				T		pf		Pf		Pn		
		q		1 1/4"	T-6	L	1	C=		Pt	11.8	Pt		
10	Down RN			1.38		F	6			Pe	0.4	Pv		Pe= 1x.433
		Q	38.0			T	7	pf	0.112	Pf	0.8	Pn		
		q				L		C=		Pt	13.0	Pt		
						F				Pe		Pv		BL-3 K=
		Q	38.0			T		pf		Pf		Pn		38/(13)^1/2 = 10.5
	2 1/2"	q	46.2	2 1/2"	E-6	L	76.33	C=		Pt	19.4	Pt		q= 10.5(19.4)^1/2
11	MAIN			2.469		F	6			Pe		Pv		
		Q	168.5			T	82.33	pf	0.104	Pf	8.6	Pn		
	3"	q		3"	E-7	L	179	C=		Pt	28.0	Pt		
12	MAIN			3.068		F	7			Pe		Pv		
		Q	168.5			T	186	pf	0.036	Pf	6.7	Pn		
	3 1/2"	q		3 1/2"	3xE-8	L	80	C=		Pt	34.7	Pt		
13	MAIN			3.548		F	24			Pe		Pv		
	TO RISER	Q	168.5			T	104	pf	0.018	Pf	1.9	Pn		
	TOP OF	q		4"	CV-22	L	70	C=		Pt	36.6	Pt		
14	RISER TO			4.062	GV-2	F	24			Pe	30.3	Pv		Pe= 70x.433
	BOTTOM	Q	168.5			T	94	pf	0.009	Pf	0.8	Pn		
										PF	67.7			

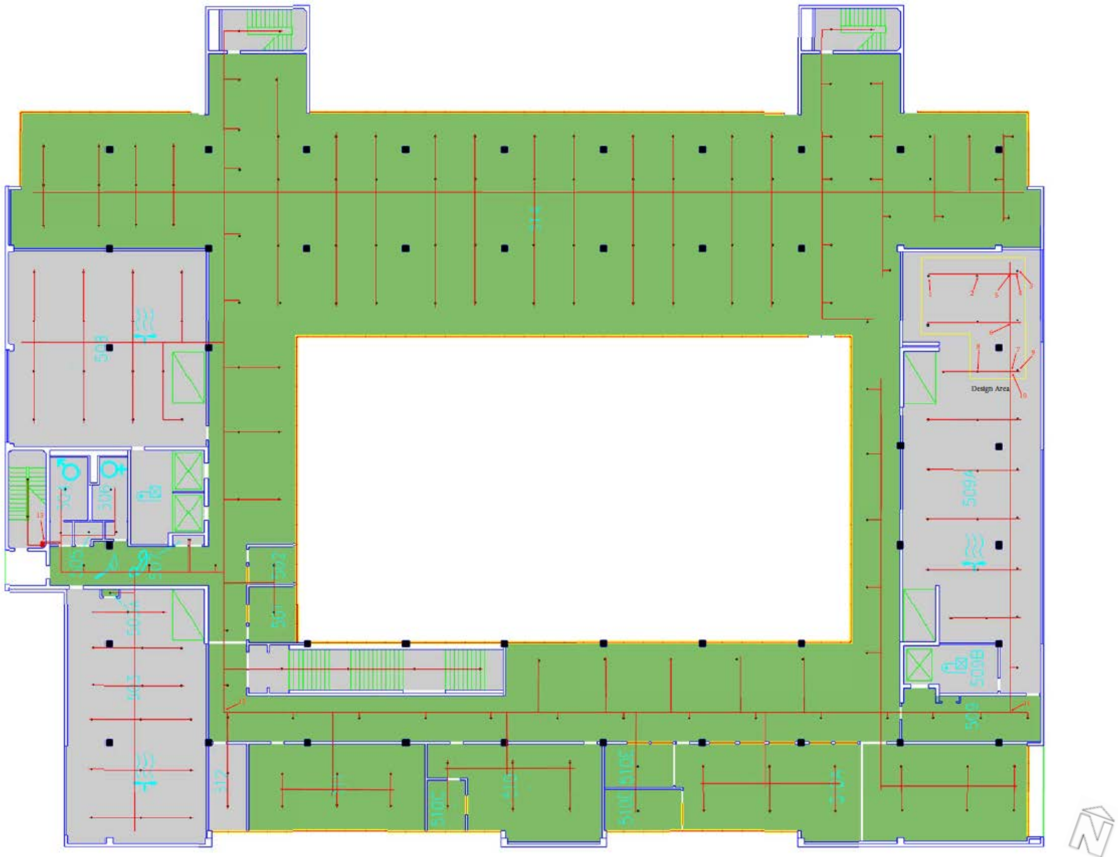


Figure 8- Kennedy Library 5th Floor Sprinkler System Layout with Nodes Identified

The calculated hydraulic demand of the sprinkler system is 168.5 gpm at a pressure loss of 67.7 psi.

3.1.2.7. Hose Stream Allowance

Kennedy Library has a Class II standpipe system (1 ½ in. hose connections). The inside hose stream allowance for multiple hose connection installation is 100 gpm (Section 11.1.6.3, NFPA 13[(3)]). The total combined inside and outside hose stream allowance for a Ordinary Hazard Occupancy is 250 gpm (100 gpm for inside hose and 150 gpm additional for outside hose). The required water supply duration is 60 minutes.

3.1.3. STANDPIPE SYSTEMS

The IBC's[(1)] requirement for a standpipe system based on building height states that "Class III standpipe systems shall be installed throughout buildings where the floor level of the highest story is located more than 30 feet above the lowest level of fire department vehicle access" (Section 905.3.1). The floor level of the highest floor (5th floor) in Kennedy Library is 56 ft above the lowest level of fire department vehicle access thus requiring it to be equipped with a Class III standpipe system based on current requirements. If Kennedy Library were a sprinklered building, a Class I system would be required.

3.1.3.1. Installed System

The standpipe system is assumed to be a Class II system based on the piping size. The wet standpipe system is a series of 6 standpipes, supplied by a 4 in. main that is piped around the perimeter of the building on the ground floor. The standpipes supply thirty hose stations; five stations per standpipe. The most remote hose station is on the 5th floor, 505 ft of pipe away from where the supply enters the building. The pressure at the most remote station, with a flow of 50 gpm, was calculated to be 39.5 psi at the time of design. The standpipe system also supplies 21 sprinklers that are installed in various rooms throughout the building. The riser diagram of the standpipe system is shown in Figure 9.

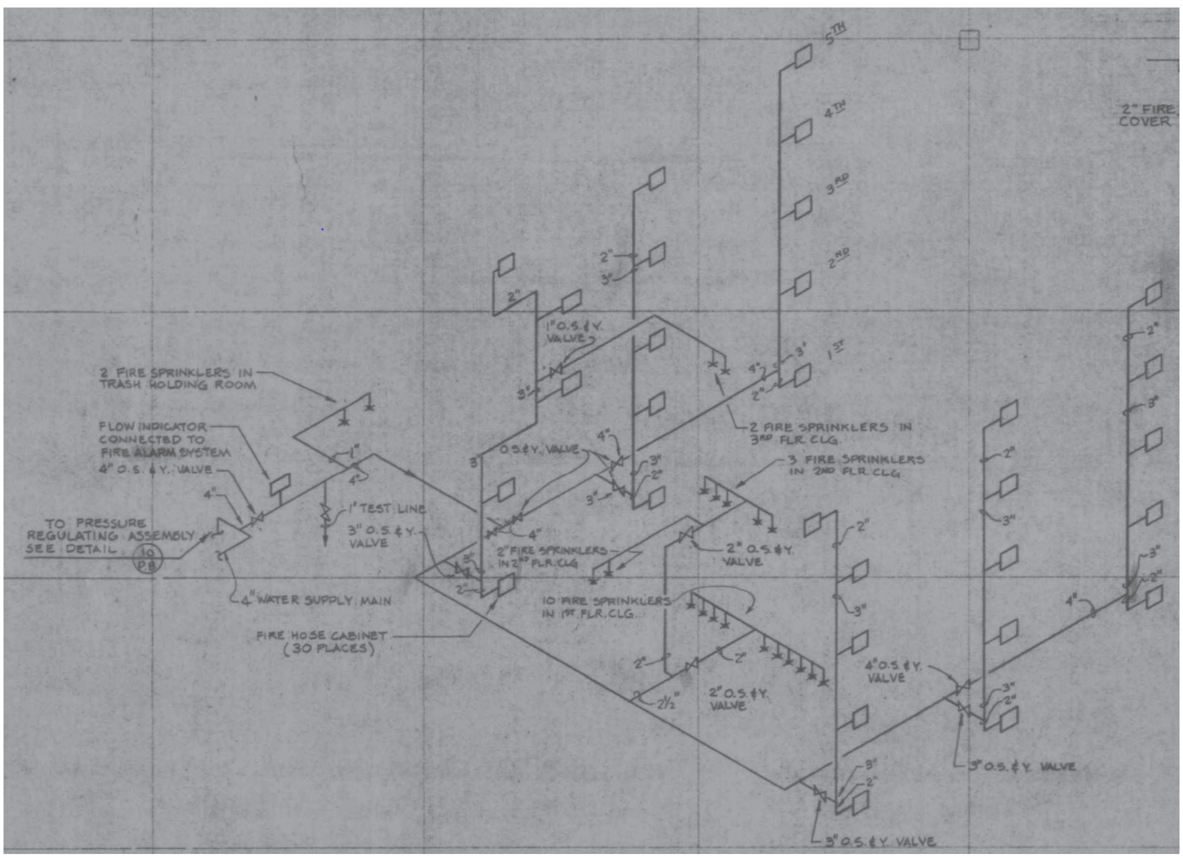


Figure 9- Standpipe System Riser Diagram

The minimum design pressure for a Class II system is 65 psi at the outlet of the hydraulically most remote hose station (Section 7.8.1, NFPA 14[4]). The minimum flow rate for a Class II system is 100 gpm at the hydraulically most remote hose connection.

3.1.3.2. Design Criteria for New System

The standpipe system installed in Kennedy Library at its construction does not meet the current code requirements for new systems. The IBC(1) requires that the system be Class III. This is based on the height of the building and the fact that it is not sprinklered.

A Class III system must provide 2 ½ in. hose connections to supply water for use by fire departments and those trained in handling heavy fire streams (section 5.3.2.1, NFPA 14(4)). The IBC(1) requires that a 2 ½ in. hose connection be provided for every floor level above or below grade in each interior exit stairway. A Class III system must provide 1 ½ in. hose connections to supply water for use by trained personnel. The IBC(1) requires that a 1 ½ in. hose connection be accessible and located so that all portions of the building are within 30 feet of a nozzle attached to 100 feet of hose.

3.1.3.3. Fire Department Connection

There are two Fire Department Connections (FDC) connected to the standpipe. One of the FDCs is on the north side of the building, outside of stairwell #2 and the other is on the west side of the building, outside of stairwell #4.

3.1.4. WATER SUPPLY ANALYSIS

Water supply data was gathered from a nearby fire hydrant supplied from the underground water supply loop. The water supply data is provided in Table 8. The water supply is shown on Figure 10. The sprinkler demand and hose stream allowance for the sprinkler system designed for the library's fifth floor is shown with a red line. The standpipe system demand is shown with a blue line.

Table 8- Water Supply Data

Flow (gpm)	Pressure (psi)
0	80
1210	60

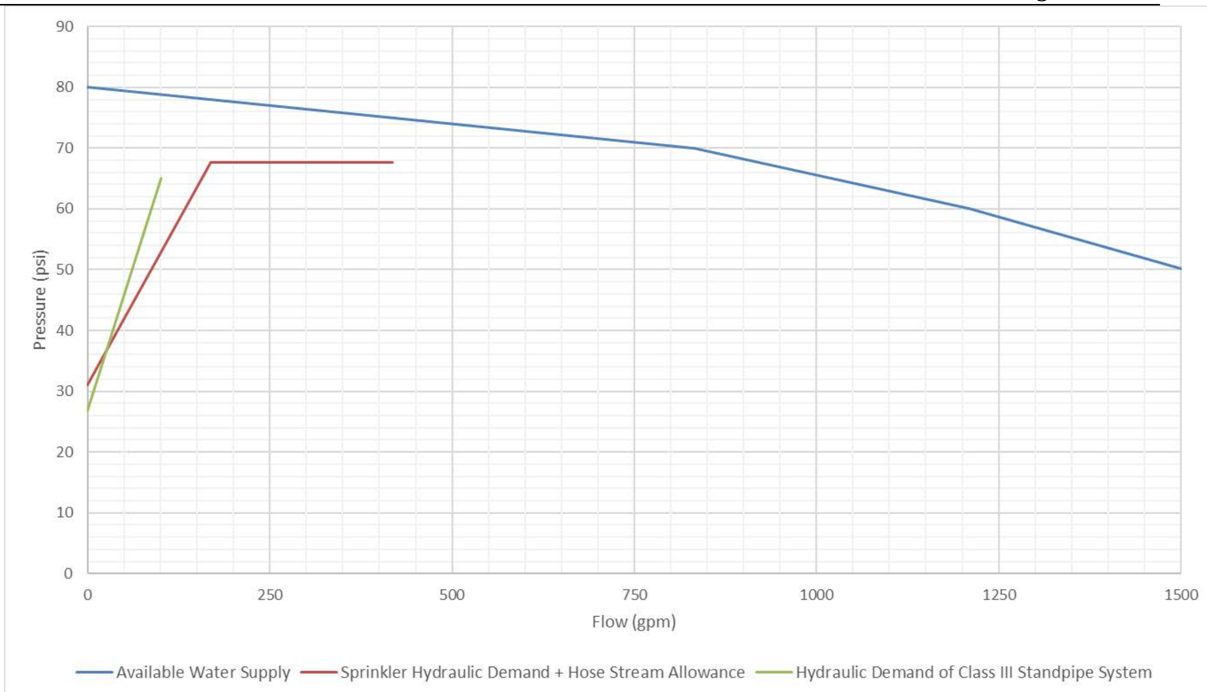


Figure 10- Kennedy Library Water Supply Curve

The water supply available is sufficient to supply either of the analyzed demands. If an automatic sprinkler system were to be installed, the water supply would not be required to be altered.

The standpipe system aids in the emergency response to Kennedy Library in the event of a fire. The lack of automatic sprinklers is not optimal for building protection. The reason that automatic sprinklers were not required or installed when the building was constructed is due to the robust passive fire protection features of the building which are discussed in the following section.

3.1.5. FIRE BARRIER ASSEMBLIES

3.1.5.1. Vertical Openings

In buildings where floors are separated from the others by a fire barrier, there are restrictions on vertical shafts that penetrate multiple floors. These restrictions are meant to prevent the spread of smoke and fire from the point of ignition to other areas where occupants may not be aware that an event is occurring. The Kennedy Library has a total of 12 vertical shafts that penetrate multiple floors. The building is equipped with 5 stairwells, 3 elevator shafts and 4 utility shafts.

Stairway #1 is the main stair that rises through the center of the building. Stairway #1 is protected by 2-hour fire resistant barriers. This stair can only be credited as a means of egress for the occupants on the 5th floor level. Stairwell #1 cannot be credited as a means of egress for other floor levels due to the fact that entrances to stairway #1 on the 3rd and 4th floor levels are protected with sliding fire doors which do not meet NFPA 101(8) requirements. Only the doorway between the 5th floor level and stairway #1 is in accordance with means of egress requirements of NFPA 101(8).

Stairways #2 and #3 serve floors 1-5, stairway #4 serves floors 2-5 and discharges outside at the 1st floor; as vertical openings that connect four or more stories the walls are required to be rated for 2 hours and the doors are required to be 90-minute rated. Stairway #5 serves floors 2-4 and discharges outside at the 1st floor. It connects 3 stories or less and is only required to be rated for 1 hour, however it was constructed to the same specifications as the other perimeter stairwells; 2-hour fire resistance rated construction. Stairwell #s 2-5 are compliant with Section 7.1 of NFPA 101(8). There are 3 elevator and 4 utility shafts in the Kennedy Library. These shafts fall under and meet the same vertical opening requirements as the stairwells.

3.1.5.2. Exit Access

Corridors that are used for exit access and serve an area with an occupant load greater than 30 must be separated from other parts of the building by walls having not less than 1-hour fire resistance rating (Section 7.1.3.1 of NFPA 101(8), and section 1020 of IBC(1)). Kennedy Library has exit access corridors leading to stair #4 on floors 1-5, however, the north wall that separates the corridors from the bathrooms is not constructed of fire rated material and therefore does not meet the requirements. There is one other exit access corridor in the building, it is on the second floor and leads to stairway #5. The corridor is constructed of materials that are 2-hour fire resistance rated. This corridor is a component of the means of egress for occupants on the 5th floor using stairway #1.

3.1.6. FIRE EXTINGUISHERS

Fire extinguishers are installed in the facility in accordance with NFPA 10(1). Fire extinguishers must be inspected and maintained in accordance with NFPA 10. All library employees must be trained in the operation of fire extinguishers.

3.1.7. SMOKE CONTROL

Smoke control features are not required for existing assembly occupancies by NFPA 101. Smoke control features would not be required if Kennedy Library were being designed and constructed in accordance with the IBC(1). All of the air handling units serving Kennedy Library are equipped with duct detectors which shutdown the unit once activated. This function limits the spread of smoke throughout the building. There is an exhaust vent at the top of stairway #1. It can be manually activated to open at the 1st floor.

3.2. FACILITY SAFETY

3.2.1. NFPA 101, LIFE SAFETY ANALYSIS

3.2.1.1. Occupant Load

Kennedy Library is classified as assembly type occupancy with incidental business use (less than 10% of total). The minimum width of a building's exits is based on the building's occupant load. The occupant load is based on the use of the building and the floor area. NFPA 101 provides occupant load factors for different uses. These load factors are to be divided by the floor area. The resulting number is the occupant load. The facility has a calculated occupant load of 2625 as shown in Table 9. Table 10 shows the occupant load factors which were used.

Table 9- Kennedy Library Calculated Occupant Loads

Calculated Occupant Load

Floor	Area/sf (Business)	Occupant Load	Required No. of Exits	Available No. of Exits
1st	50,445 (1,337)	851	3	7
2nd	46,631 (3,234)	555	2	4
3rd	41,595 (0)	460	2	4
4th	35,586 (377)	381	2	4
5th	34,172 (2,116)	378	2	4
Total:	208,429 (7,064)	2625		

Table 10- Occupancy Load Factors

Occupancy Load Factors Used

Use	sf/person
Library stack areas	100
Library reading rooms	50 net
Business	100
Incidental storage, mechanical, electrical rooms	100

3.2.1.2.Egress Capacity

Egress capacity is based on capacity factors that are given in the NFPA 101(8) and the International Building Code, and is a function of egress width. The capacity factors from Section 7 of NFPA 101 are shown in Table 11. The capacity factors are used to estimate the maximum number of occupants that can pass through a pathway without impeding flow beyond an acceptable threshold. The width used when calculating egress capacity is the narrowest point (limiting factor) in the path of egress.

Table 11- Egress Capacity Factors

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

Kennedy library is code compliant in regards to egress capacity. The first floor is equipped with seven exits. The second through fifth floors have access to four exits. The number of exits for each floor meets the requirements of Section 13.2.4, NFPA 101[(8)], which are as follows:

1. An occupant load of 600 or less occupants must have a minimum of two separate means of egress.
2. An occupant load greater than 600 but less than 1,000 must have a minimum of three separate means of egress.

Table 12 shows the door widths, how many of each door width is on each floor, the capacity factor used, and the egress capacity served.

Table 12- Calculated Egress Capacities

Calculated Egress Capacities

Floor	Exit width at narrowest point	Capacity Factor	Egress Capacity (No. of Occ. Served)
1st	144"	0.2	720
1st	72"	0.2	360
1st	48" (*3)	0.2	720
1st	36" (*2)	0.2	360
2nd-4th	48" (*4)	†	660
5th	48" (*4)	†	660

† Determined through use of calculation for capacity increase for stairs greater than 44" in width, section 7.3.3.2, NFPA 101, 2015 ed.

Exits shall be located, and exit access shall be arranged, so that exits are readily accessible at all times. NFPA 101(8) states in Section 7.5 that where more than one exit from a building or portion thereof is required, the exits shall be remotely located from each other and arranged to minimize the likelihood that more than exit may be blocked. Where two exits are required, they shall be located at a distance from one another not less than one-half the length of the maximum overall diagonal dimension of the area being served. The maximum overall diagonal dimension for the first floor, which is the floor with the greatest dimensions, is 333 feet. The exit separation on all floors is greater than 200 feet and all rooms required to have at least two exits have adequate separation. The Kennedy Library meets the criterion of Section 7.5, Arrangement of Means of Egress.

See Attachment 1 for building floor layouts with exits identified.

3.2.1.3. Door Leaf Swing Direction

Section 7.2.1.4.2 of NFPA 101(8) requires that door leaves of the side-hinged type, swing in the direction of egress travel where the doors serve a room or area with an occupant load of 50 or more. The courtyard on the first floor has a calculated occupant load of 85. The courtyard does not have direct access to the exterior of the building; therefore, the courtyard occupants must exit through the interior of the building. There are two doorways that serve the courtyard and both are equipped with side-hinge type doors which swing against the direction of egress travel. This condition is a deficiency and it should be corrected.

3.2.1.4. Marking of Means of Egress

The requirements of NFPA 101(8) (Section 7.10.1.2) for exit signs are as follows:

1. Exits, other than main exterior exit doors that obviously and clearly are identifiable as exits, shall be marked by an approved sign that is readily visible from any direction of exit access.
2. Horizontal components of the egress path within an exit enclosure shall be marked by approved exit or directional exit signs where the continuation of the egress path is not obvious.

See Attachment 1 for building floor plans showing locations of exit signs.

3.2.1.5. Travel Distance

In existing assembly occupancies, Section 13.2.6 of NFPA 101(8) restricts the maximum travel distance to the nearest exit, to 200 feet in unsprinklered buildings.

There are several means of egress from each floor level spread out on the perimeter of the building allowing for exits to be within the maximum travel distance from any point in the library. Kennedy Library is configured in accordance with the NFPA 101(8) requirements for maximum permitted travel distance.

3.2.1.6.Common Path of Travel and Dead-Ends

In existing assembly occupancies, Section 13.2.5 of NFPA 101(8) permits a common path of travel of 20 feet where the path serves any number of occupants and a common path of 75 feet where the path serves 50 or fewer occupants. Section 13.2.5 of NFPA 101(8) restricts the length of dead-end corridors to a maximum of 20 feet.

There are several means of egress from each floor level and there are no dead-end corridors in the building. Kennedy Library is configured in accordance with the NFPA 101(8) requirements for common path of travel and dead-end corridors.

Kennedy Library, with the exception of the door swing direction issue in the courtyard, is in compliance with the egress requirements of NFPA 101. The doors should be reconfigured so that their swing direction aligns with what is stated in NFPA 101. The means of egress features are more than adequate and will provide for a satisfactory level of safety as long as the building occupants are aware of all egress features.

3.3. FIRE PROTECTION PROGRAM ANALYSIS

3.3.1. FIRE PREVENTION

3.3.1.1. Smoking Restrictions

Smoking is not permitted in the building or within 20 feet of any building entrance/exit.

3.3.1.2. Electrical Equipment

Space heaters will not be permitted within the building.

Extension cords will only be used for temporary purposes. Ensure that an appropriate extension cord (amperage capacity) is being used with any equipment.

Surge protectors are not to be plugged into surge protectors (daisy-chained).

3.3.1.3. Building Walkdowns

Building walkdowns should be performed at the beginning and ending of each day. The purpose of the walkdowns is as follows:

- Ensure electrical equipment is shut off.
- Ensure building occupants have exited the building.
- Check for smoke.
- Check for excessive combustible loading.
- Ensure exits are not blocked.

3.3.2. EMERGENCY REPORTING ANALYSIS

3.3.2.1. Reporting of Emergencies

In the event of an emergency, library staff will call 911 to report the emergency and provide the dispatch will relevant information. In the event that the building must be evacuated, library staff will also activate a pull station to sound the building fire alarm.

Upon discovery of an unwanted fire or evidence of a previous unwanted fire that had apparently been extinguished, library staff will immediately notify the fire department.

3.3.2.2. Crowd Managers

Two crowd managers will be on duty at all times of library operation. The crowd managers and crowd manager supervisors will receive training in crowd management techniques.

The training for the duties and responsibilities of crowd managers will include the following:

- Understanding crowd manager roles and responsibilities
- Understanding safety and security hazards that can endanger public assembly
- Understanding crowd management techniques
- Introduction to fire safety and fire safety equipment
- Understanding methods of evacuation and movement
- Understanding procedures for reporting emergencies
- Understanding crowd management emergency response procedures
- Understanding the paths of travel and exits, facility evacuation and emergency response procedures and, where provided, facility shelter-in-place procedures
- Familiarization with the venue and guest services training
- Other specific event-warranted training

3.3.2.3. Fire Drills

The library staff will be trained and drilled in the duties they are to perform in case of fire, panic, or other emergency to effect orderly exiting. When conducting drills, emphasis shall be placed on orderly evacuation rather than on speed. Drills shall be held at expected and unexpected times and under varying conditions to simulate the unusual conditions that can occur in an actual emergency. Drill participants shall relocate to a predetermined location and remain at such location until a recall or dismissal signal is given.

3.3.2.4. Emergency and Evacuation Drill Frequency

Emergency drills will be performed semi-annually with a full evacuation drill performed at least annually.

3.3.2.5. Elevator Use

The elevators in Kennedy library are not designed for emergency evacuation and should not be used in the event of a fire or when the fire alarm is activated.

3.3.3. EQUIPMENT AND FURNISHINGS PROCUREMENT

3.3.3.1. Electrical Equipment

All electrical equipment must be listed by an OSHA Nationally Recognized Testing Laboratory (NRTL). A list of NRTLs can be found on the OSHA website.

3.3.3.2. Furnishings

Furnishings must meet the requirements of NFPA 101(8) and NFPA 701(9).

3.3.4. OWNER RESPONSIBILITIES

The owner or their designee is responsible for the following items:

- Compliance with the adopted fire code.
- Notification of the authority having jurisdiction prior to a change of occupancy of the building.
- Supply tests or test reports at the request of the authority having jurisdiction as proof of compliance with the fire code.
- Correct deficiencies as directed by the authority having jurisdiction.
- The maintenance of any device, equipment, system, condition, arrangement, level of protection, fire-resistive construction, or any other feature that is required for compliance with the provisions of the fire code.
- Maintain records of all maintenance, inspections, and testing of fire protection systems, fire alarm systems, smoke control systems, emergency evacuation and relocation drills, emergency plans, emergency power, elevators, and other equipment.

3.3.5. INSPECTION, TESTING AND MAINTENANCE

3.3.5.1. Automatic Fire Alarm and Detection

All inspection, testing and maintenance and impairment procedures shall be implemented in accordance with NFPA 72(6), Chapter 14. All components and systems shall be tested to verify they function as intended, and on a frequency in accordance with NFPA 72(6), Sections 14.3 thru 14.5. Qualification of inspection, testing and maintenance personnel is based on the requirements of the authority having jurisdiction.

Table 13 identifies the required frequencies of inspection, testing and maintenance of system components.

Table 13- Inspection and Testing Frequencies for Fire Alarm and Detection Systems

Component	Inspection Frequency	Testing Frequency
Primary power supply	Annually	Annually
Trouble signals	Semi-annually	Annually
Digital alarm communicator transmitter	Annually	Annually
Batteries	Semi-annually	Annually
Duct detectors	Semi-annually	Annually
Electromechanical releasing devices	Semi-annually	Annually
Manual fire alarm boxes	Semi-annually	Annually
Smoke detectors	Semi-annually	Annually
Supervisory signal devices	Quarterly	Annually
Waterflow devices	Quarterly	Annually
Audible notification devices	Semi-annually	Annually
Visible notification devices	Semi-annually	Annually

3.3.5.2. Water-Based Suppression

All inspection, testing, maintenance and impairment procedures shall be implemented in accordance with NFPA 25(5) (Section 4.1). All components and systems shall be tested to verify they function as intended, and on a frequency in accordance with NFPA 25(5) (Section 4.6). Qualification of inspection, testing and maintenance personnel is based on the requirements of the authority having jurisdiction.

See NFPA 25(5) for tables detailing required ITM frequencies of water-based suppression systems.

3.3.5.3. Fire Extinguishers

NFPA 10(1) requires a monthly inspection of fire extinguishers. Facility employees may perform the monthly extinguisher inspection. The inspection is a quick check that a fire extinguisher is in its designated place, that it has not been actuated or tampered with, and that there is no obvious physical damage or condition to prevent its operation. A checklist with the type and location of all extinguishers is to be maintained. Fire extinguishers are to have inspection tags attached and the inspector is to initial and date the tag so as to maintain a record of inspections. If an extinguisher is found to be missing, depressurized or damage, the inspector will notify campus maintenance.

NFPA 10 requires annual maintenance of fire extinguishers. Personnel performing fire extinguisher maintenance are required to be certified by an organization acceptable to the authority having jurisdiction. A contractor will be retained to perform fire extinguisher maintenance when necessary. A new inspection tag will be attached to each fire extinguisher during its annual maintenance.

3.3.5.4. Emergency Lights and Exit Signs

Emergency lights and exit signs are to be inspected monthly. Emergency lights and exit signs are to be tested annually by verify operation after 90 minutes with the primary power source deactivated. Records are to be kept for all inspections and tests.

See Attachment 1 for building floor plans showing locations of exit signs.

3.3.6. IMPAIRMENT PROCEDURE

3.3.6.1. General Impairment Requirements

The owner or their designee must correct or repair impairments that are found during system inspections. Corrections and repairs must be performed by qualified personnel. Measures shall be taken during the impairment to ensure that increased risks are minimized and the duration of the impairment is limited.

A tag shall be used to indicate that a system, or part thereof, has been removed from service. The tag shall be posted at each fire department connection and the system control valve, and other locations required by the authority having jurisdiction indicating which system, or part thereof, has been removed from service.

An outline of common water-based system deficiencies, and whether they require an impairment to be placed on the system, can be found in Table A.3.3.7 of Appendix A of NFPA 25[5].

3.3.6.2. Preplanned Impairments

All preplanned impairments shall be authorized by the owner or their designee. Before authorization is given, the impairment coordinator shall be responsible for verifying that the following procedures have been implemented:

1. The extent and expected duration of the impairment have been determined.
2. The areas or buildings involved have been inspected and the increased risks determined.
3. Recommendations have been submitted to management or the property owner or designated representative.
4. Where a required fire protection system is out of service for more than 10 hours in a 24-hour period, the impairment coordinator shall arrange for one of the following:
    a. Evacuation of the building or portion of the building affected by the system out of service
    b. An approved fire watch.
    c. Establishment of a temporary water supply.

   d. Establishment and implementation of an approved program to eliminate potential ignition sources and limit the amount of fuel available to the fire
5. The fire department has been notified.
6. The insurance carrier, the alarm company, property owner or designated representative, and other authorities having jurisdiction have been notified.
7. The supervisors in the areas to be affected have been notified.
8. A tag impairment system has been implemented.
9. All necessary tools and materials have been assembled on the impairment site.

3.3.6.3. Unplanned Impairments

Emergency impairments shall include, but are not limited to, system leakage, interruption of water supply, frozen or ruptured piping, and equipment failure. When an emergency impairment occurs the owner or their designee will implement the steps outlined in section 3.7.5.2 of this report.

3.3.6.4. Restoring System to Service

When all impaired equipment is restored to normal working order, the impairment coordinator shall verify that the following procedures have been implemented:

1. Any necessary inspections and tests have been conducted to verify that affected systems are operational.
2. Supervisors have been advised that protection is restored.
3. The fire department has been advised that protection is restored.
4. The property owner or designated representative, insurance carrier, alarm company, and other authorities having jurisdiction have been advised that protection is restored.
5. The impairment tag has been removed.

3.3.7. RECORDS

Records of all inspections, tests, maintenance activities, system impairments, staff training, and drills are to be kept and maintained for the time period required by the authority having jurisdiction. Records must be made available to the authority having jurisdiction upon request. Records shall indicate the procedure performed (e.g., inspection, test, or maintenance), the organization that performed the work, the results, and the date. As-built system installation drawings, hydraulic calculations, original acceptance test records, and device manufacturer’s data sheets shall be retained for the life of the system. When emergency impairments occur, emergency action shall be taken to minimize potential injury and damage.

3.4. SUMMARY

The primary fire protection features of Robert Kennedy Library are the passive, fire-resistant construction features, the means of egress and the FAS. These features provide a safe environment for the building occupants. The deficiencies noted were the potentially inadequate FAS notification coverage, the lack of an EVACS in accordance with the IBC, and the incorrect door swing direction of the doorways serving the courtyard on the first-floor level. It is recommended that these issues be analyzed in more detail and corrected. Kennedy Library is in compliance with prescriptive requirements besides the stated deficiencies. Based on this analysis, the building owner and occupants can be assured of an adequate level of safety in the event of a fire.

4.0 PERFORMANCE-BASED ANALYSIS

This analysis is a performance-based evaluation of the fire protection features of the Robert E. Kennedy Library. The objective of this analysis is to determine whether building occupants are exposed to an unreasonable level of risk in the event of a fire. This report will outline three design fire scenarios that are based on three of the fire scenarios suggested in NFPA 101[(8)]. The selected design fire scenarios represent three scenarios that will present a significant challenge to the life safety features of the building.

4.1. OCCUPANT CHARACTERISTICS

When it comes to performance-based design of egress one of the most significant factors to consider are the occupant characteristics. These characteristics can be supported by evidence but are sometimes based on assumptions. The calculated response and evacuation time will be influenced greatly based on the characteristics. In a college campus library environment, occupants are likely to be young, mobile, spaced at a low density, familiar with the building and alert.

Familiarity with the building, while likely leading to a decrease in travel time, may result in an increase in pre-movement time. The reason for this is that occupants who are familiar with their surroundings will not be as concerned with finding a safe means of egress, where as an occupant who is unfamiliar with the building may have a higher level of anxiety and search out an exit as soon as possible. Like-wise with young and mobile occupants, they will be more confident in their ability to escape if conditions worsen quickly. If the density of people is low, occupants will likely not feel threatened by competition to reach a safe means of egress which may lead to lingering for longer periods.

4.2. PERFORMANCE-BASED EGRESS

4.2.1. DETECTION AND NOTIFICATION

The first step in calculating egress time is determining the amount of time between ignition of the fire and notification of the building occupants. The detection and notification time will be determined in the computer-based modeling.

4.2.2. PRE-MOVEMENT TIME

The second step in calculating egress time is determining the pre-movement time; the amount of time between occupants being alerted to an emergency situation and the occupants beginning their evacuation. There are six factors that are part of a person's decision whether or not to evacuate:

1. Recognition – This is the beginning of the occupant's awareness of the fire event. They may not always indicate that there is a fire, and the way in which an occupant is notified also has a part to play in this. Again, either visual or audio cues will help the occupant differentiate the event.

2. Validation – The next part in which the occupant defines if there is an event or not. During this process the occupant may try to obtain more information about the event; the person is aware something is happening, but needs to make sure that the event is life threatening or not.
3. Definition – This is where the occupant defines the event in relation to themselves. Basically, the occupant is processing the event in terms of how large is the fire and how can I get out.
4. Evaluation – This is the coping portion of the six steps. At this point, the occupant realizes that there is a fire and has come to the conclusion that they need to leave. The occupants' brain is now saying, "Okay, there is a fire, I need to leave. Where is the fire, how close am I to it, and how/do can I get out?"
5. Commitment – This is the commitment to leave the area or stay in place from the occupant. Sometimes, in situations like hospitals (where there is a defend-in-place strategy) the occupant may not want to leave the area. A high-rise building where the fire is many stories below (this would be if the occupant were even notified) is another case of where the occupant might choose to stay instead of leave.
6. Reassessment – It is at this time where the occupants stress and anxiety levels are the highest. The greater the magnitude of the event the higher the reassessment process will occur over and over in the occupant's mind. The decision of where to go or what to do come to the forefront of the occupants reasoning and take precedence over every other thought.

The SFPE Handbook(11) provides estimated pre-movement times for many types of occupancies. The estimated times are based on the typical characteristics of the average occupant for the type of occupancy. There are currently no generally accepted methods of modeling pre-evacuation times. The estimated pre-movement time for buildings such as the Kennedy Library, without engineered or administrative controls in place to accelerate it, is 4 minutes. This estimated pre-movement time is intended for occupants who are not intimate with ignition. The pre-movement activities are likely going to be evaluating the actions of other occupants in the vicinity and gathering personal belongings.

4.2.3. EVACUATION TIME

The second step in calculating egress time is determining the time it takes for occupants to exit the building from the time they began moving. The four basic characteristics noted in the NFPA 101(8) that influence evacuation time are:

1. Sensibility to physical cues, which is the ability to sense the sounding of an alarm and can also include discernment and discrimination of visual and olfactory cues in addition to auditory emanations from the fire itself.
2. Reactivity, which is the ability to interpret cues correctly and take appropriate action and can be a function of cognitive capacity, speed of instinctive reaction, or group dynamics; might need to consider reliability or likelihood of a wrong decision, as in situations where familiarity with the premises influences wayfinding.

3. Mobility (speed of movement), which is determined by individual capabilities, as well as crowding phenomena, such as arching at doorways.
4. Susceptibility to products of combustion, which includes metabolism, lung capacity, pulmonary disease, allergies, or other physical limitations that affect survivability in a fire environment.

The occupants of the Kennedy Library are likely to have high levels of sensibility, reactivity, and mobility.

4.2.4. HYDRAULIC FLOW CALCULATIONS

The egress calculations that are available are based on limited research data from observed evacuation drills and surveys of people who evacuated a building during a real event. When egress design is based on developed egress calculations, there are many assumptions made when defining the parameters. The following are common assumptions made when calculating egress:

- All persons will start to evacuate at the same instant.
- Occupant flow will not involve any interruptions caused by decisions of the individuals involved.
- All or most of the persons involved are free of disabilities that would significantly impede their ability to keep up with the movement of a group.

These assumptions tend to optimize egress times and therefore will tend to underestimate actual egress times. There are many aspects of egress, which cannot be reasonably anticipated, to develop a reliable method of calculation.

The four basic elements used to calculate movement are:

1. Flow (people (P)/sec): # of persons that pass a specific point per unit time
2. Speed (m/s): distance traveled per unit time
3. Density (people (P)/m^2): Number of people per unit area
4. Specific flow or “flux” (people (P)/s/m): Flow rate / unit width of the path

4.2.4.1. Calculated Egress Time for Kennedy Library

Calculation parameters:

1. Stairway #4 is used because it is an example of the maximum capacity/travel distance that is expected.
2. The occupant load, above the 1st floor that will use stairway #4 for egress, is 476.
3. There are 5 floors.
4. The floor to floor height is 14 ft.
5. All of the exit stairways in the building are 48 in. wide (tread width).
6. Stair risers are 7 in. tall and treads are approximately 11 in. wide.
7. There are two 6 ft by 8.5 ft landings per floor in each stairway.

8. The exit discharge has a nominal width of 48 in.
9. The stairway entrance door has a nominal width of 36 in.
10. The first floor does exit through the stairways.

Assumptions:

The exit access for stairway #4 is the most constricted and therefore will have the longest evacuation time. Queuing will occur; therefore the specific flow will be the maximum specific flow. All occupants begin egress at the same moment. The exits will be used in the optimum balance.

Estimate flow capacity through stairway exit door:

From Table 14 (Table 59.5 from the SFPE HB) [11], the maximum specific flow through a 36 in. door is 24 person/min/ft effective width. Using equation 59.8 from the SFPE HB the flow through the exit door can be calculated as 36x2 = 72 persons/min. Equation 59.8 is as follows- $F_c=F_sW_e$, with F_c being the calculated flow, F_s being the specific flow, and W_e being the effective width of the component being traversed.

Table 14- Maximum Specific Flow

		Maximum specific flow	
Exit route element		Persons/min/ft of effective width	Persons/s/m of effective width
Corridor, aisle, ramp, doorway		24.0	1.3
Stairs			
Riser	Tread		
(in.)	(in.)		
7.5	10	17.1	0.94
7.0	11	18.5	1.01
6.5	12	20.0	1.09
6.5	13	21.2	1.16

Estimate flow capability of stairway #4:

From Table 15 (Table 59.1 of the SFPE Handbook)[11], the effective width of the stairway is 48-12 = 36 in. (3 ft). The effective width of each door is 36-12 = 24 in. (2 ft). The maximum specific flow for the stairway (using Table 59.5, SFPE Handbook[11]) is 18.5 persons/min/ft effective width. Specific flow equals maximum specific flow. Therefore, using Equation 59.8, the flow from the stairway is limited to 18.5x3 = 55.5 person/min. Since the flow capacity of the stairway is less than the flow capacity of the exit door, the flow is limited by the stairway.

Table 15- Boundary Layer Widths

Exit route element	Boundary layer (in.)	(cm)
Stairways—wall or side of tread	6	15
Railings, handrails[a]	3.5	9
Theater chairs, stadium benches	0	0
Corridor, ramp walls	8	20
Obstacles	4	10
Wide concourses, passageways	<18	46
Door, archways	6	15

[a]Where handrails are present, use the value if it results in a lesser effective width

Estimate the speed of movement for estimated stairway flow:

Using Equation 59.5 from the SFPE HB [(11)], the speed of movement down the stairs is 212-(2.86x212x0.175) = 105 ft/min. Equation 59.5 is as follows- S=k-akD, with S being the Speed along line of travel, D being the Population density in persons per unit area, and k being a constant as shown as determined using Table 59.2 from the SFPE HB.

The travel distance between floors (using the conversion factor from Table 16 or Table 59.3, SFPE HB[(11)]) is 24x1.85 = 44.4 ft on the stair slope plus 8.5 ft travel on each of two landings, for a total floor-to-floor travel distance of 44.4+(2x8.5) = 61.4 ft. The travel time for a person moving with the flow is 61.4/105= 0.58 min/floor.

Table 16- Conversion Factors for Relating Line of Travel Distance

Stairs riser (in.)	Tread (in.)	Conversion factor
7.5	10.0	1.66
7.0	11.0	1.85
6.5	12.0	2.08
6.5	13.0	2.22

1 in. = 25.4 mm

Estimate building evacuation time:

If all of the occupants in the building begin evacuation at the same time, stairway #4 can discharged 55.5 persons/min. The 476 occupants above the first floor will require approximately 8.58 minutes to pass over the lowest stair. An additional 0.58 minutes of travel time per floor is required, giving a minimum evacuation time of approximately 11 minutes [8.58+(4*0.58)=10.9] from the beginning of movement to exit from the building. When calculating the discharge time from the exit stairway, the number off occupants served increases from 476 to 586; however, the flow through the stairway exit is calculated at 72 persons/min so the evacuation time for the occupants descending the stairs is greater than the combined number of occupants from all floors passing through the stairway exit door.

4.3. TENABILITY CRITERIA

Tenability relates to the environmental conditions of a space and what effect they have on the normal functions of a living creature, generally humans. The amount of time that it takes for the occupants to evacuate is the Required Safe Egress Time (RSET). The amount of time that is available for occupants to evacuate prior to conditions becoming untenable is the Available Safe Egress Time (ASET). For the occupants to be able to evacuate safely, the RSET must be less than the ASET. In other words, the occupants must be able to evacuate prior to the environment becoming untenable. Various documents provide examples of performance criteria that can be used to determine whether a building design will be tenable up to the time evacuation is completed. Several criteria are discussed in Appendix A of NFPA 101(8).

4.3.1. SMOKE LAYER HEIGHT

In Section A.5.2.2 of NFPA 101(8), criterion for smoke layer height is discussed. The objective of this methodology is to demonstrate that the time it takes for the smoke layer to descend to a level below 72 inches is greater than the estimated evacuation time. It is stated in Section A.5.2.2 that, though 60 inches is often the height used in calculations for safe egress below a smoke layer, that 72 inches will have less of an effect on travel speed; making calculated egress times a better reflection of reality. The majority of Kennedy Library is large, open spaces with 168-inch ceilings (the drop ceilings are at 108 inches). Due to this, it will take a long time for the smoke layer to descend below 72 inches, allowing substantial time for evacuation.

Calculating the time it will take for the smoke layer to descend below the height of 72 inches in each space, compared to the calculated time it would take for the occupant load of the given space to evacuate, would determine whether this method is a valid approach to determining the tenability performance of Kennedy Library.

4.3.2. VISIBILITY

Visibility is a common criterion used when analyzing tenability. If building occupants cannot see then they cannot locate an exit. One factor that this methodology is dependent on is the occupants' familiarity with the location, which can have a significant impact on the ability to locate an exit. This factor is discussed in Chapter 61 of the SFBE Handbook. Table 17 below is from Chapter 61 and shows that occupants who are unfamiliar with their environment are expected to need at least 13 meters of visibility to locate an exit while occupants who are familiar are only expected to need at least 4 meters of visibility.

Table 17- Visibility Reduction Resulting in Loss of Wayfinding

Degree of familiarity with inside of building	Smoke density (extinction coefficient)	Visibility
Unfamiliar	0.15 1/m	13 m
Familiar	0.5 1/m	4 m

Visibility reduction resulting from smoke development will not be uniform from floor to ceiling. The average height of men is just under 6 feet tall while the average height of women is around 5 and a-half feet. A height of 6 feet above the floor will be used as a conservative height for measuring visibility reduction. A visibility reduction of both 13 meters and 4 meters will be analyzed.

4.3.3. TEMPERATURE

Temperature increase is another consequence of fire that can lead to an untenable condition. Chapter 63 of the SFPE Handbook(11) goes into extensive detail about the effects of high temperatures on humans. Figure 11 from Chapter 63 shows a temperature curve for human tolerance for exposure to convected heat.

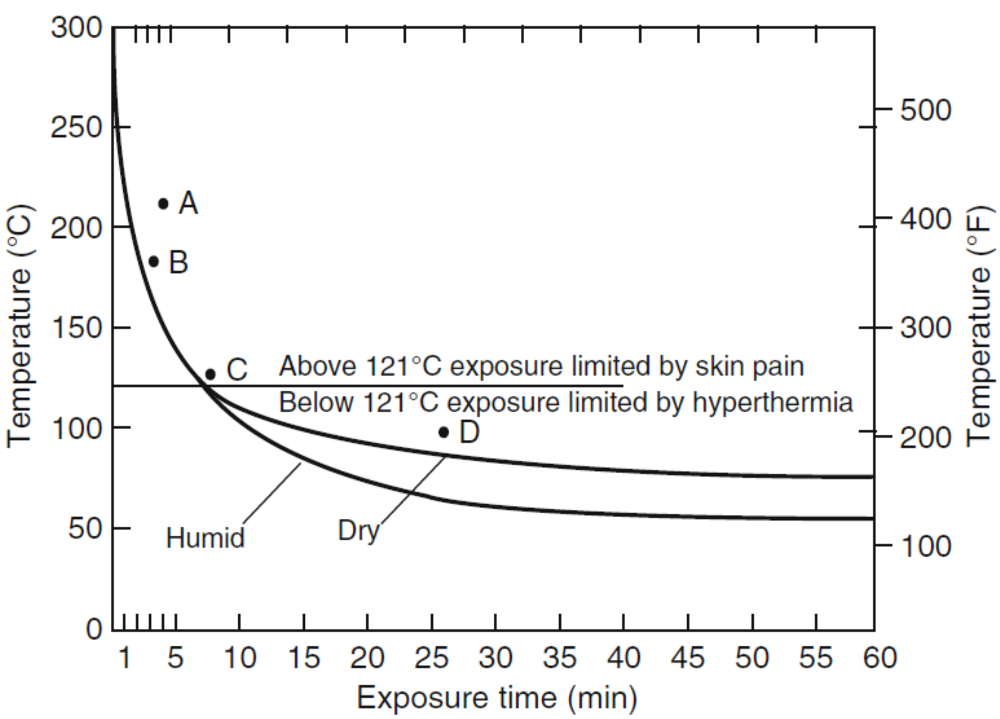


Figure 11- Incapacitation due to Temperature Exposure

Tolerance is based on the factors of exposure time, temperature and humidity level. The RSET was calculated in Section 4.2 of this report to be 15 minutes (not including time required for detection and notification). Based on the tolerance curve in Figure 11, exposure to a temperature of 80ºC for 15 minutes would be untenable. The temperature will be measure at 6 feet above the floor, similar to the methodology used in Section 4.3.3 of this report. Toxicity is another criterion that is often used when analyzing tenability, however, visibility reduction is most often the first tenability criterion to be exceeded, therefore toxicity was not analyzed.

4.4. FUEL ANALYSIS

The fuel load of the building is primarily paper products and furniture consisting of metal. wood, fabrics and foams. The most important characteristic of a fuel is the Heat Release Rate (HRR). Once a HRR for a fuel has been determined through fire testing, a reasonable estimation of how the fuel will burn in a fire can be made. Because HRR is so important, much fire testing has been performed on materials and objects to gather this much-needed data. It is not possible to determine the flammability characteristics of an object based on the flammability characteristics of the object's component's, therefore, research must be done to determine how objects will burn. The empirical data derived from this research is one of the primary tools utilized when postulating how a fire will evolve in a space. The design fire scenarios analyzed in this report include the burning of the following objects

- Trash can
- Work station
- Table
- Office chair
- Upholstered chair
- Shelving units containing paper products

The data derived from the research that has been performed on these objects will be used as inputs for the design fire scenarios analyzed in this report.

4.4.1. TRASH CAN

Trash cans are a common place for fires to initiate. As such, they are commonly used in design fires as the fuel for a fires incipient stage. In a research project performed by NIST (Madrzykowski & Kerber(16), the oxygen consumption method of determining HRR was used to analyze two small trash cans burning.

The trash can specimens used in the research were 10.5-inch-tall, polypropylene containers weighing approximately 0.32 kg. The specimens were filled with approximately 0.32 kg. of newspaper. The two specimens were burned individually with the intent of obtaining average data points. The specimens were identified as "Trash Container 1" and "Trash Container 2". The following figures (Figure 12 and Figure 13) are photographs taken during the burn tests, at 100 second intervals.

Figure 3.2-1. Trash container 1, ignition

Figure 3.2-2. Trash container 1, 100 s after ignition

Figure 3.2-3. Trash container 1, 200 s after ignition

Figure 3.2-4. Trash container 1, 300 s after ignition

Figure 3.2-5. Trash container 1, 400 s after ignition

Figure 3.2-6. Trash container 1, at peak heat release rate, 406 s after ignition

Figure 3.2-7. Trash container 1, 500 s after ignition

Figure 3.2-8. Trash container 1, 600 s after ignition

Figure 12- Photographs of Trash Container 1 Burn Test at 100 Second Intervals

Figure 3.2-9. Trash container 2, ignition

Figure 3.2-10. Trash container 2, 100 s after ignition

Figure 3.2-11. Trash container 2, 200 s after ignition

Figure 3.2-12. Trash container 2, 300 s after ignition

Figure 3.2-13. Trash container 2, at peak heat release rate, 363 s after ignition

Figure 3.2-14. Trash container 2, 400 s after ignition

Figure 3.2-15. Trash container 2, 500 s after ignition

Figure 3.2-16. Trash container 2, 600 s after ignition

Figure 13- Photographs of Trash Container 2 Burn Test at 100 Second Intervals

The average peak HRR of the trash cans was 32 kW and the average total energy released for the trash cans was 16.1 MJ. Figure 14 is the HRR-time curves for the trash cans.

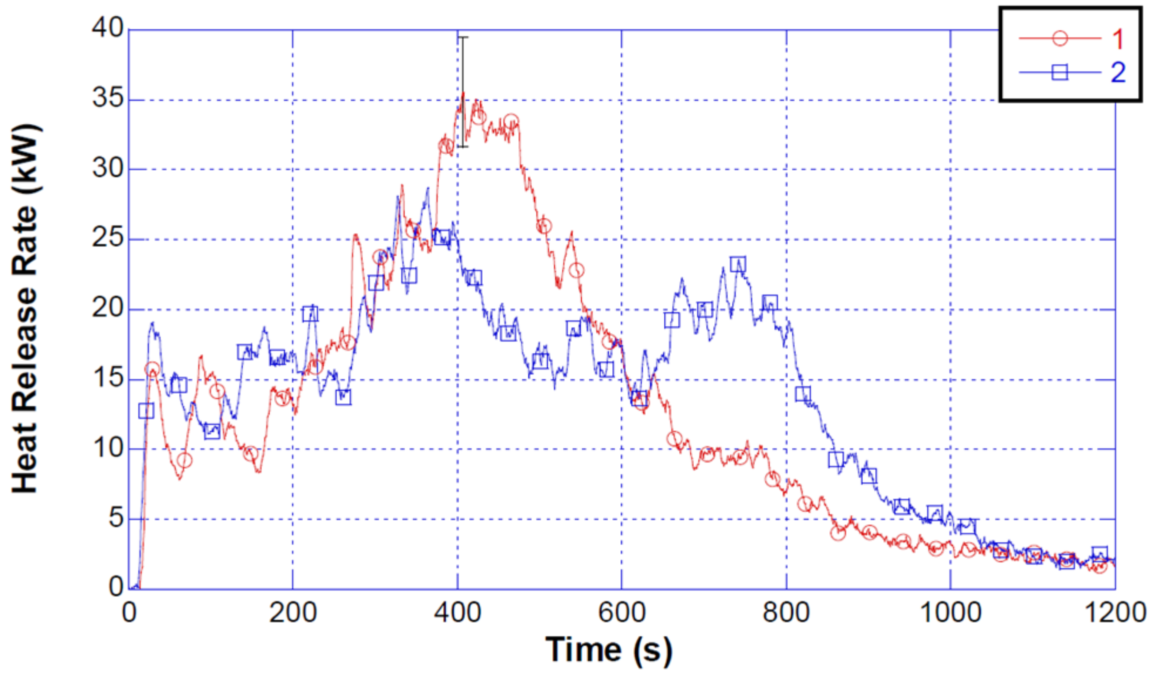


Figure 14- HRR-Time Curve for Trash Can 1 and Trash Can 2

The difference in the HRR-time curves of the trash cans can be attributed to the non-identical configurations of the trash can contents. The heat flux-time curves and the mass loss-time curves are shown in Figure 15 and Figure 16.

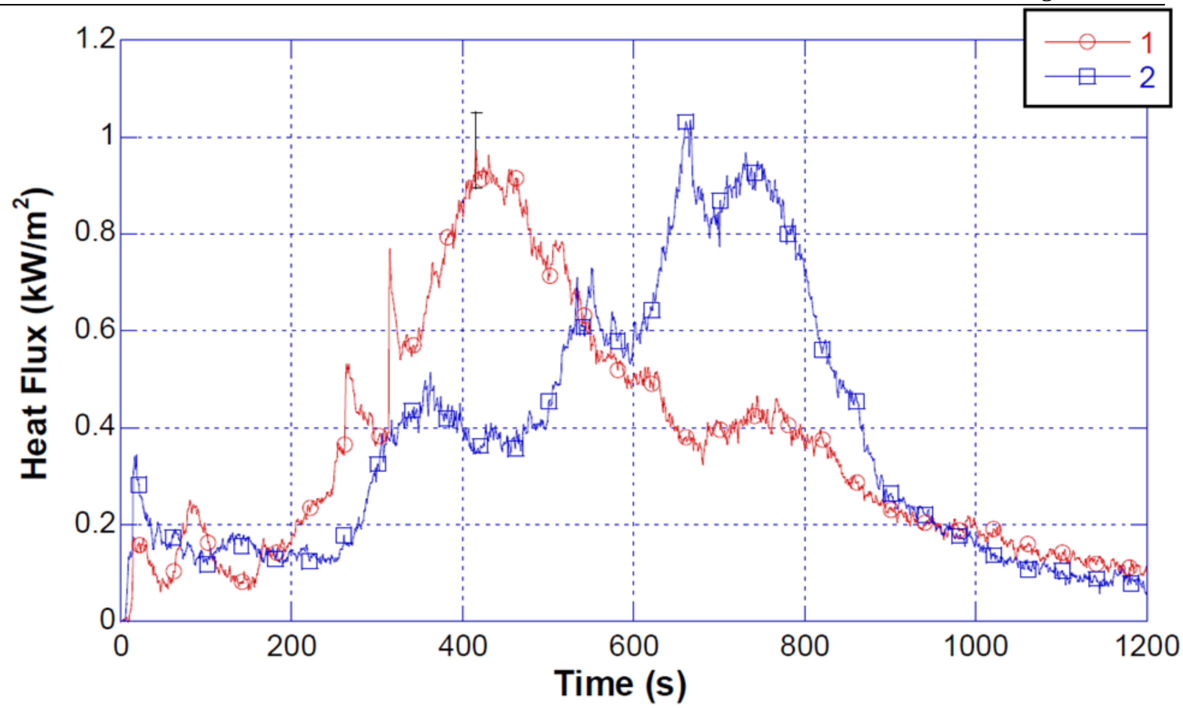


Figure 15- Heat Flux-Time Curve for Trash Can 1 and Trash Can 2

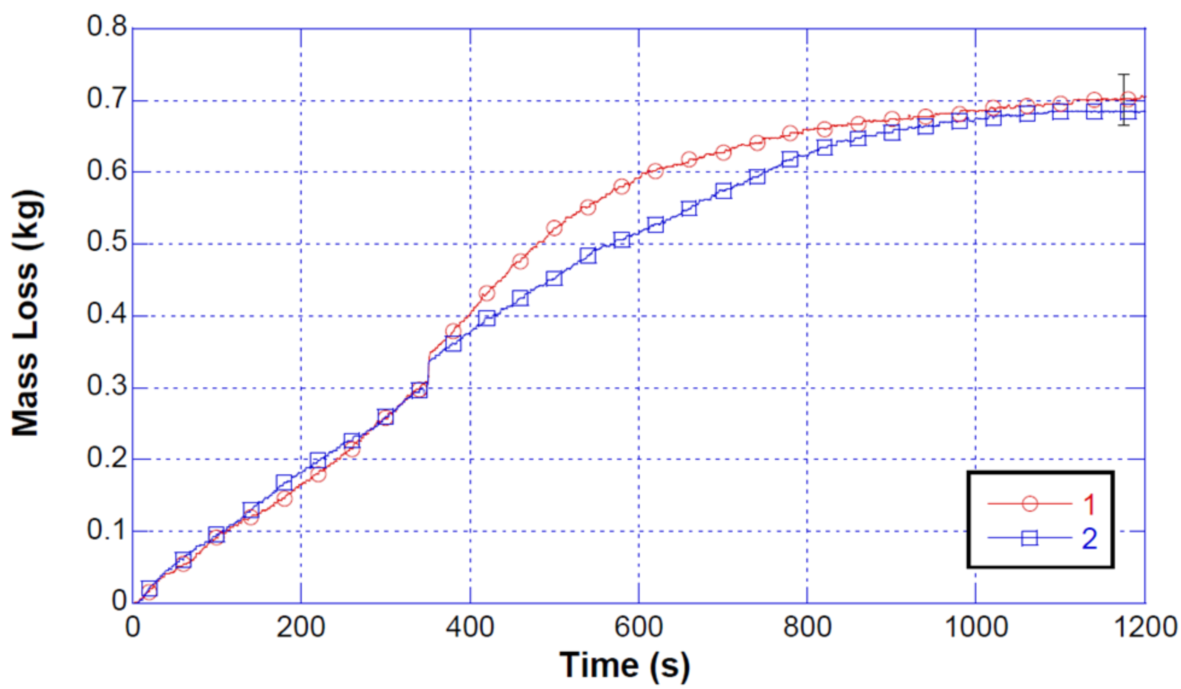


Figure 16- Mass Loss-Time Curve for Trash Can 1 and Trash Can 2

The peak heat flux at 1m from the edge of the burning specimens was approximately 1 kW/m^2. The average heat of combustion of the specimens was determined by dividing the total energy released by the mass loss. In both specimen burns, more than 95% of the fuel was consumed within 1200 s after ignition. The calculated average heat of combustion was 23.75 MJ/kg. The soot yield of polypropylene is 0.059 g/g. The soot yield of wood (nearest material to paper) is 0.015 g/g. Soot yields are obtained from the SFPE Handbook(11).

4.4.2. WORK STATION

A work station is a common fuel package in libraries; it is a fuel package that consists of many materials. It must therefore be tested full-scale to obtain relevant data. A research study was published in 1988 (Walton & Budnick, 1988)(17) that detailed the burn tests of work stations in which the oxygen consumption method was used to determine the HRR.

The work station consisted of a desk and a book case constructed of 5/8 in. thick particle board covered with plastic laminate. The desk was 60 in. tall by 49 in. wide by 23.5 in. deep and weighed 58 kg. The desk was loaded with 45 kg of paper products. The book case was 72 in. tall by 36 in. wide by 12 in. deep and weighed 46 kg. The book case was loaded with 72.5 kg of paper products.

Two work stations were tested, test 101 and test 102. The average maximum HRR of the two tests was 1.63 MW. The average total energy release of the two tests was 1275 MJ. The calculated average heat of combustion was 5.75 MJ/kg. The HRR-time curves of test 101 and test 102 is shown in Figure 17. The soot yield of wood is 0.015 g/g.

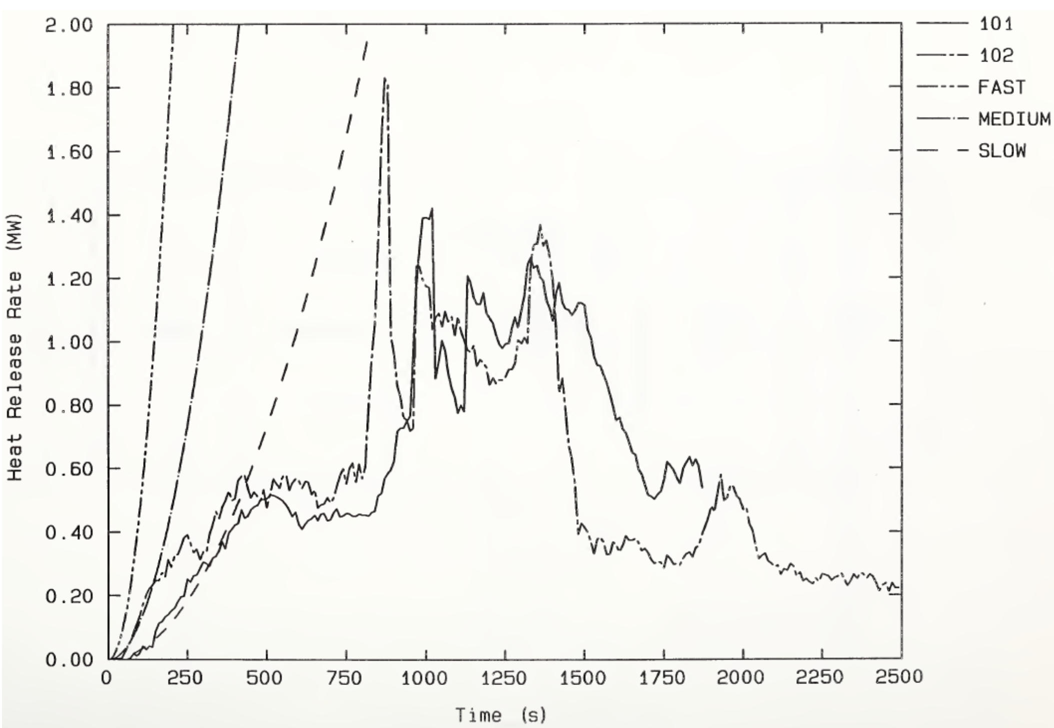


Figure 17- HRR-Time Curves of Tests 101 and 102

4.4.3. OFFICE CHAIR

Office chairs are often constructed with polymeric foams and fabric resulting in them being a substantial contribution to fire loading. The Combustion Behavior of Upholstered Furniture (CBUF) program has documented the results of many furniture burn tests. The burn test of a swivel chair (Sundstrom, 1995)[(18)] constructed with 100% fire resistant polyester and high-resiliency foam, using the furniture full-scale calorimeter method resulted in the data shown in Table 18.

Table 18- Flammability Characteristics of Swivel Chair

Scalar	Value
Peak heat release (kW)	860.7
Total heat release (MJ)	303.7
Initial mass (g)	19500
Total massloss (g)	10670
Average heat of combustion (MJ/kg)	28.460

The soot yield of polyester is 0.09 g/g (average of two polyesters identified in SFPE Handbook[(11)]). The soot yield of polyurethane foam is 1.88 g/g (average of four PU foams identified in SFPE Handbook[(11)]).

4.4.4. UPHOLSTERED CHAIR

An upholstered chair was tested in the same research project as the trash cans above (Madrzykowski & Kerber, 2009)[(16)]. The chair used as a specimen in the research was 2.4 ft wide, 2.5 feet deep and 2.4 ft high. The chair had a wooden frame, polyurethane foam for padding and cotton/polyester fabric. The chair had a mass of 23.3 kg. The point of ignition of the chair was on the seat cushion. A peak HRR of 1.67 MW was reached with total energy release of 305 MJ. The HRR-time curve is shown in Figure 18.

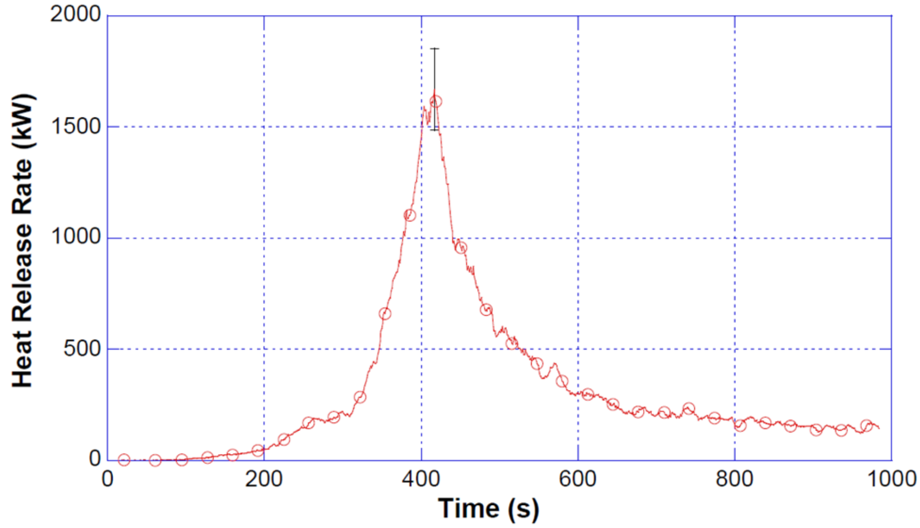


Figure 18- HRR-Time Curve of Upholstered Chair

There were three heat flux sensors in place around the chair to measure the heat flux from it burning. All three sensors measured an average peak heat flux of 25 kW/m^2. The heat flux-time curve is shown in Figure 19.

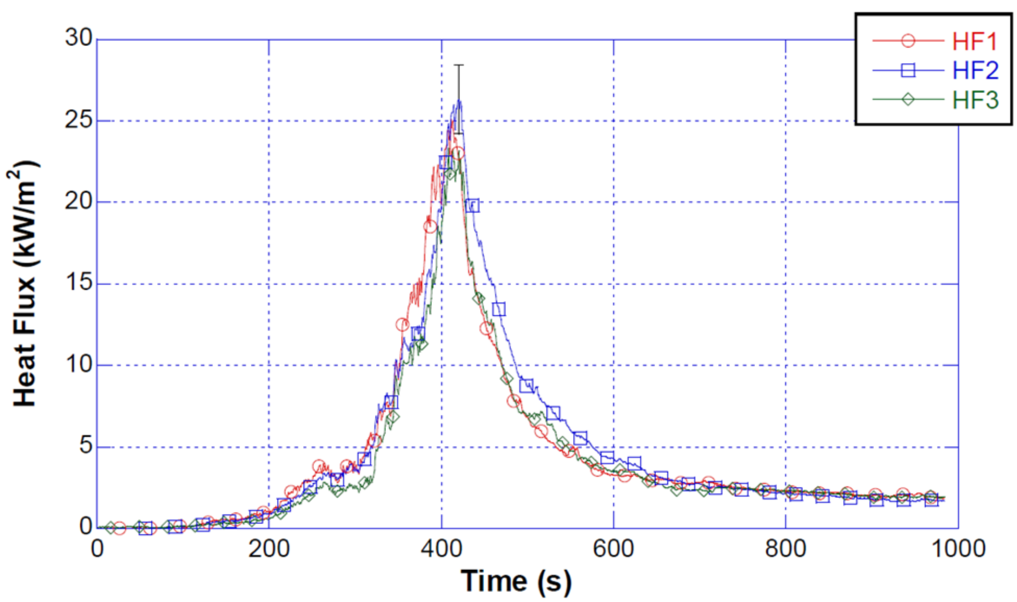


Figure 19- Heat Flux-Time Curve of Upholstered Chair

The total mass loss at 980 s was 16.5 kg. Approximately 75% of the combustible mass was consumed. The average heat of combustion of the specimens was determined by dividing the total energy released by the mass loss. The calculated average heat of combustion was 18.4 MJ/kg. The mass loss-time curve is shown in Figure 20.

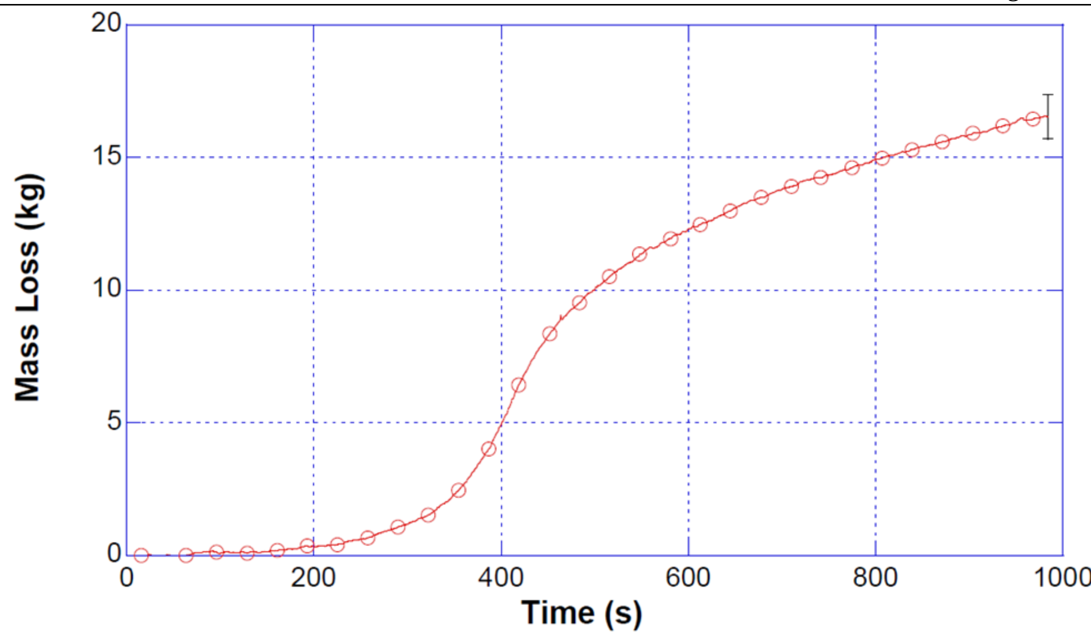


Figure 20- Mass Loss-Time Curve of Upholstered Chair

The soot yield of polyester is 0.09 g/g (average of two polyesters identified in SFPE Handbook[11]). The soot yield of polyurethane foam is 1.88 g/g (average of four PU foams identified in SFPE Handbook[11]).

4.4.5. SHELVING UNIT CONTAINING PAPER PRODUCTS

Due to the nature of libraries, they contain heavy fuel loads primarily of ordinary combustibles. Much of the space of a library is occupied by open shelving that contains paper products. The research study where burn tests were performed on work stations also performed burn tests on open shelving units which contained paper products (Walton & Budnick, 1988)[17]. In the burn tests performed on the open shelving the oxygen consumption method was used to determine the HRR.

The shelving was steel. Each unit was 71 in. tall by 36 in. wide by 18 in. deep and weighed 10 kg. A total of four shelving units were used in each test. Each unit was loaded with 120.2 kg of paper products, distributed over 6 shelves. The shelving units were placed in two parallel back-to-back sets. In test 201 the aisle width was 30 in.

The peak HRR of test 201 was 0.98 MW. The total energy release of test 201 was 318 MJ. The HRR-time curve of test 201 is shown in Figure 21.

The soot yield of wood is 0.015 g/g.

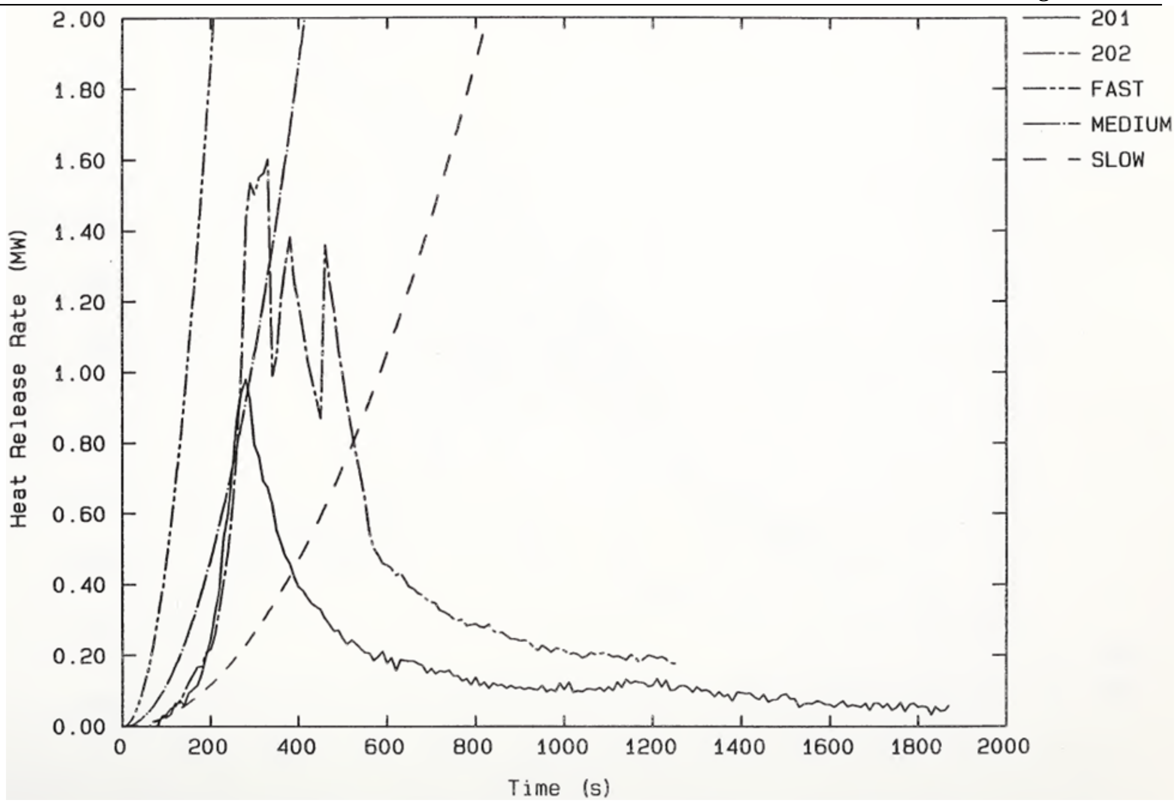


Figure 21- HRR-Time Curve of Test 201

4.5. DESIGN FIRES

The purpose of performance-based fire protection design is to utilize a unique method of fire protection, alternative to prescriptive requirements, while meeting the goals and objectives of building and fire codes. This report identifies three fire scenarios for the Robert E. Kennedy Library, based on the design fire scenario criteria provided in Chapter 5 of NFPA 101(8), that will demonstrate whether the existing fire protection features of the building are adequate to meet the objectives set forth in the applicable codes and standards.

Three different scenarios from NFPA 101(8) were chosen to evaluate different aspects of fire protection essential to life safety. The three scenarios are as follows:

- Design Fire Scenario 1, which is based on Section 5.5.3.2, and is described as-
    - It is an ultrafast-developing fire, in the primary means of egress, with interior doors open at the start of the fire.
    - It addresses the concern regarding a reduction in the number of available means of egress.
- Design Fire Scenario 2, which is based on Section 5.5.3.6, and is described as-
    - It is the most severe fire resulting from the largest possible fuel load characteristic of the normal operation of the building.

    - It addresses the concern regarding a rapidly developing fire with occupants present.
- Design Fire Scenario 3, which is based on Section 5.5.3.8, and is described as-
    - It is a fire originating in ordinary combustibles in a room or area with each passive or active fire protection system independently rendered ineffective.
    - It addresses concerns regarding the unreliability or unavailability of each fire protection system or fire protection feature, considered individually.
    - It is not required to be applied to fire protection systems for which both the level of reliability and the design performance in the absence of the system are acceptable to the authority having jurisdiction.

4.5.1. METHODOLOGY

The design fires will be based off the fuel data provided in Section 4.4 of this report. All fires will be calculated as t-squared fires, meaning that the fire will grow quadratically with each time step. The growth coefficients for rates of growth of t-squared fires, taken from the Fire Protection Handbook[10], is shown in Table 19.

Table 19- Growth Rate Coefficients for T-Squared Fires

Growth Rate	*Growth Rate Constant (kJ/sec^3 or kW/sec^2)*
Slow	0.0029
Medium	0.0117
Fast	0.0469
Ultrafast	0.1876

4.5.2. DESIGN FIRE SCENARIO 1

The fire in this scenario begins in the library's lobby at the main circulation desk which is at the foot of stairwell #1 (the main building stairwell). Stairwell #1 is a straight stairwell that connects all five floor levels. The stairwell is open to all floors. Each floor is equipped with fire doors that close when the control function holding them open is activated by a signal from the fire alarm system.

The fire begins in a trashcan underneath the circulation desk. As the trash can fire grows the circulation desk becomes involved and the fire accelerates, producing a smoke plume. The smoke is detected by the smoke detector at the second-floor stairwell which de-activates the door holders and initiates the building evacuation alarm. Due to smoke accumulation, stairwell #1 becomes untenable, reducing the number of means of egress available to the building occupants.

Due to the type of fuel involved, this fire would ordinarily be either a slow or a medium growth t-squared fire, however, the scenario from NFPA 101[8] calls for an ultra-fast fire. The growth coefficient for ultra-fast fires will therefore be used to calculate the fire growth. The fire is fuel limited and will therefore not reach flashover. Figure 22 shows the main lobby of Kennedy Library; the location of the fire scenario is within the outlined area. Figure 23 shows a closer view of the lobby area of the first floor where the circulation desk is and the proximity of stairwell #1 and the fire origin. Figure 24 shows the area of second floor level that is open to the lobby below and the location of the smoke detector.

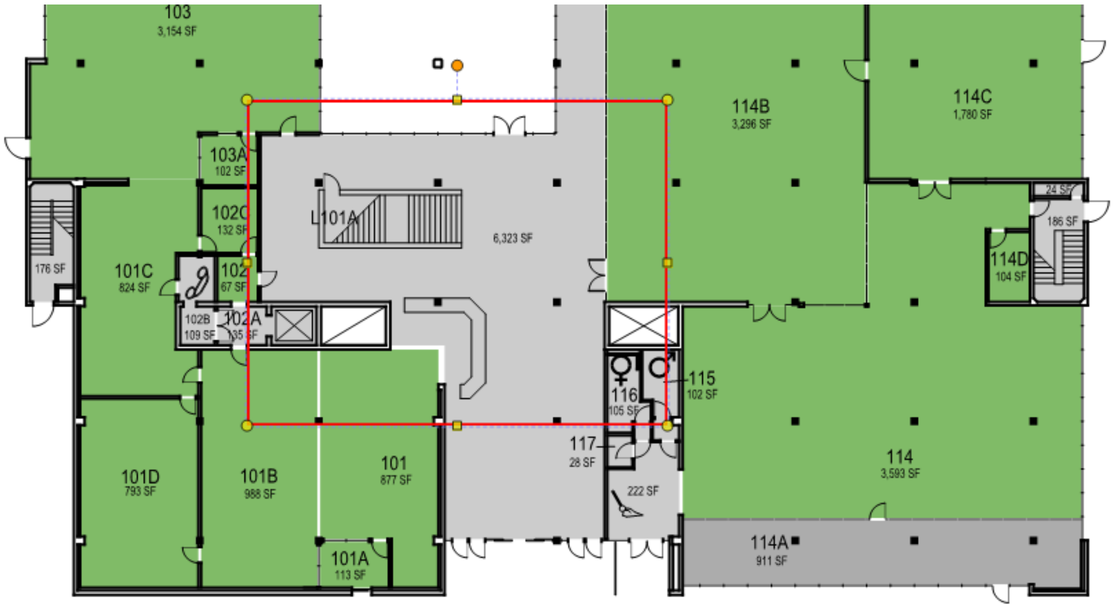


Figure 22- Main Lobby Layout on East Side of Kennedy Library

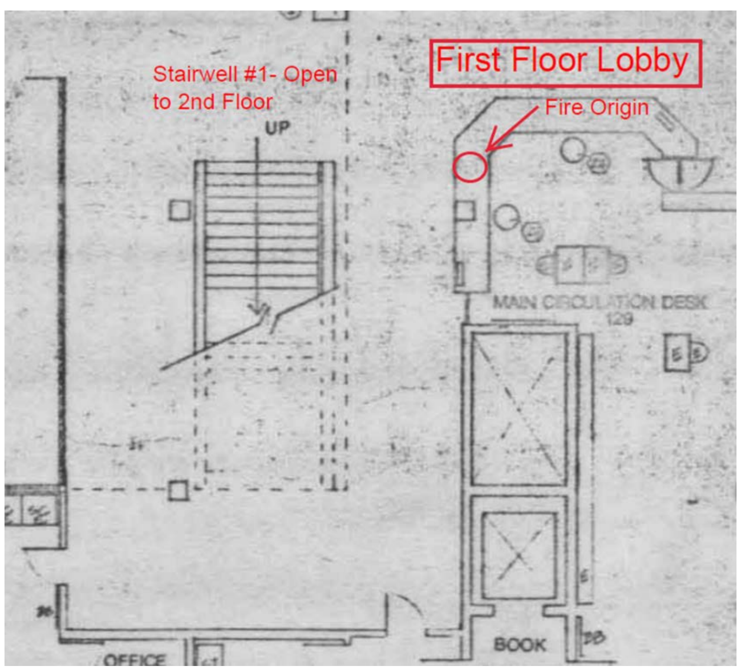


Figure 23- Kennedy Library Lobby

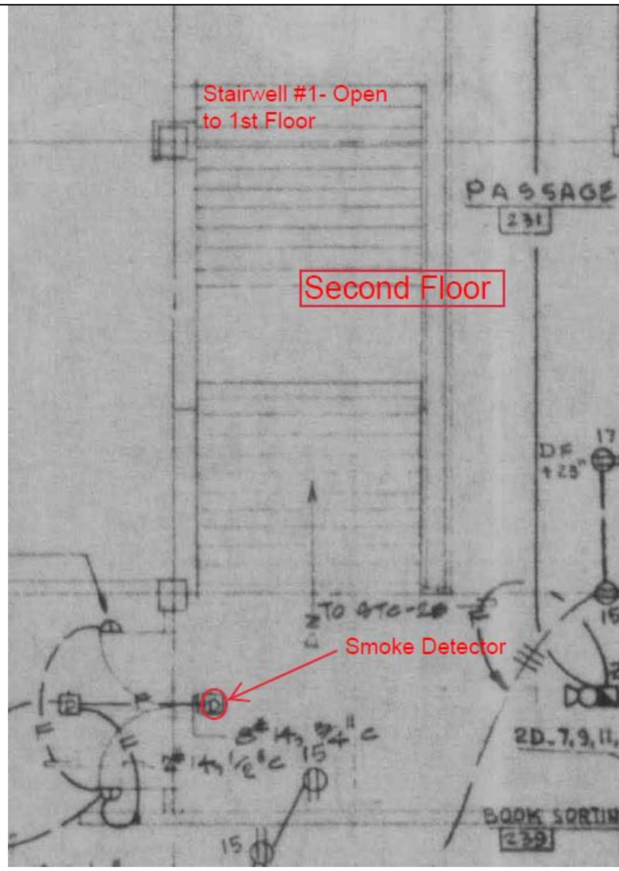


Figure 24- Open Stairwell #1, Second Floor Level

The trash can ignites at time 0. The fire continues to grow until it reaches its peak HRR. The decay of the burning fuel packages has been modeled as a reflection of the growth curve. Any excess stored energy is expended in a steady peak HRR state as shown in Figure 14. Once the trash can fire emits a sufficient heat flux, the work station (circulation desk) will ignite. The circulation desk is assumed to be equivalent to two work stations identified in Section 4.4.2 of this report. The first work station is assumed to ignite at 25 seconds after the trash can and the second work station is assumed to ignite at 25 seconds after the first (refer to). As the fire develops smoke accumulates on the ceiling eventually reaching the smoke detectors that will activate signaling the door holders to deactivate. The combined HRR-time curve of the fuel packages, which is based on an ultra-fast growing fire as described in the selected fire scenario from NFPA 101(8), is shown Figure 25.

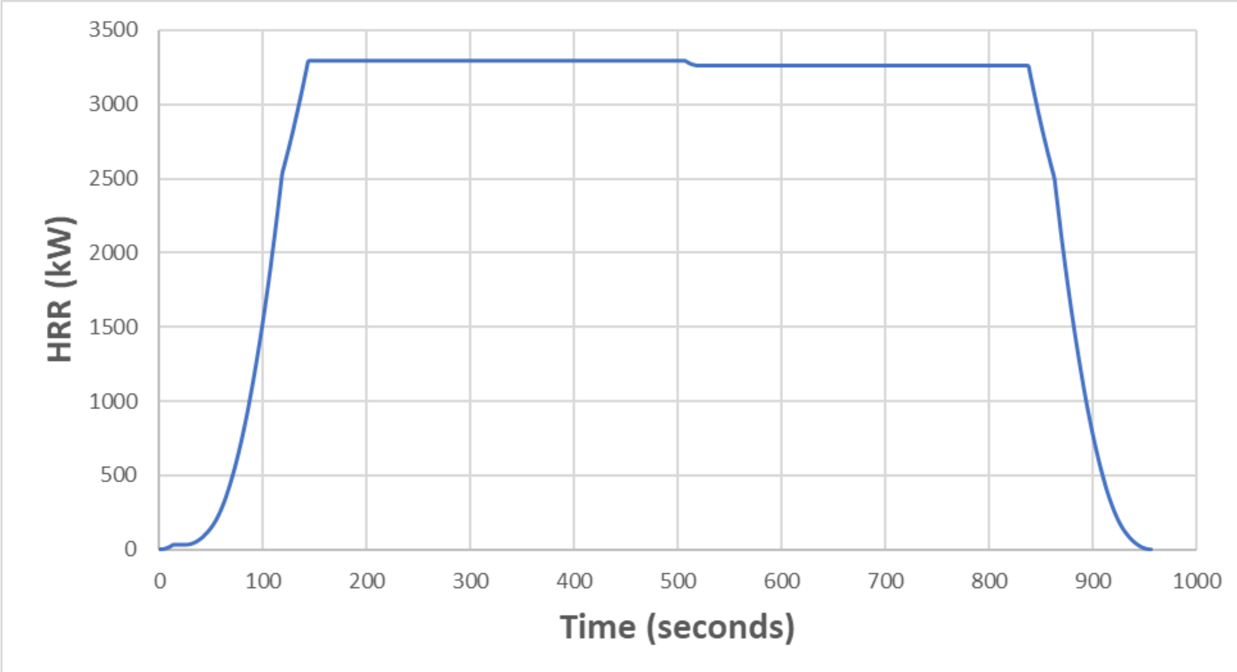


Figure 25- Fire Scenario 1 HRR-Time Curve

To determine the time until activation of the smoke detector, the smoke plume must first be modeled. The Zukoski method is used to calculate the characteristics of the fire plume. Using the HRR as input, the mass of the smoke plume is calculated using Equation 1, where $\dot{m}_a$ is the mass of air, ρ_∞ is the ambient air density, g is gravity, c_p is the specific heat of air, T_∞ is the ambient temperature, $\dot{Q}$ is the HRR and z is the height of the lower layer.

$$\dot{m}_a = 0.21\left(\frac{\rho_\infty^2 g}{c_p T_\infty}\right)^{1/3} \dot{Q}^{1/3} z^{5/3}$$ **Equation 1**

The temperature of the smoke, which is needed to determine the smoke concentration, is calculated using Equation 2 where T_s is the smoke temperature.

$$T_s = T_\infty + \left(\frac{\dot{Q}}{\dot{m}_a c_p}\right)$$ **Equation 2**

The rate of smoke production is calculated using Equation 3, where $\dot{m}_s$ is the rate of smoke production, y_s is the smoke yield of the fuel and ΔH_c is the fuels heat of combustion.

$$\dot{m}_s = y_s\left(\frac{\dot{Q}}{\Delta H_c}\right)$$ **Equation 3**

The mass concentration of the smoke is then calculated using Equation 4, where C is the mass concentration of smoke.

$$C = \dot{m}_s/\dot{m}_a$$ **Equation 4**

The percent obscuration of the smoke can then be calculated using Equation 5, where κ is the smoke extinction coefficient (assumed to be 8 m^2/g) and L is the width of the plume.

$$e^{-\kappa CL}$$ **Equation 5**

The time to detector activation is approximately 26 seconds as is shown in Figure 26. The obscuration was calculated as the sum of the obscuration of the three fuel packages. The detector activates at 3.28% obscuration, deactivating the door holder.

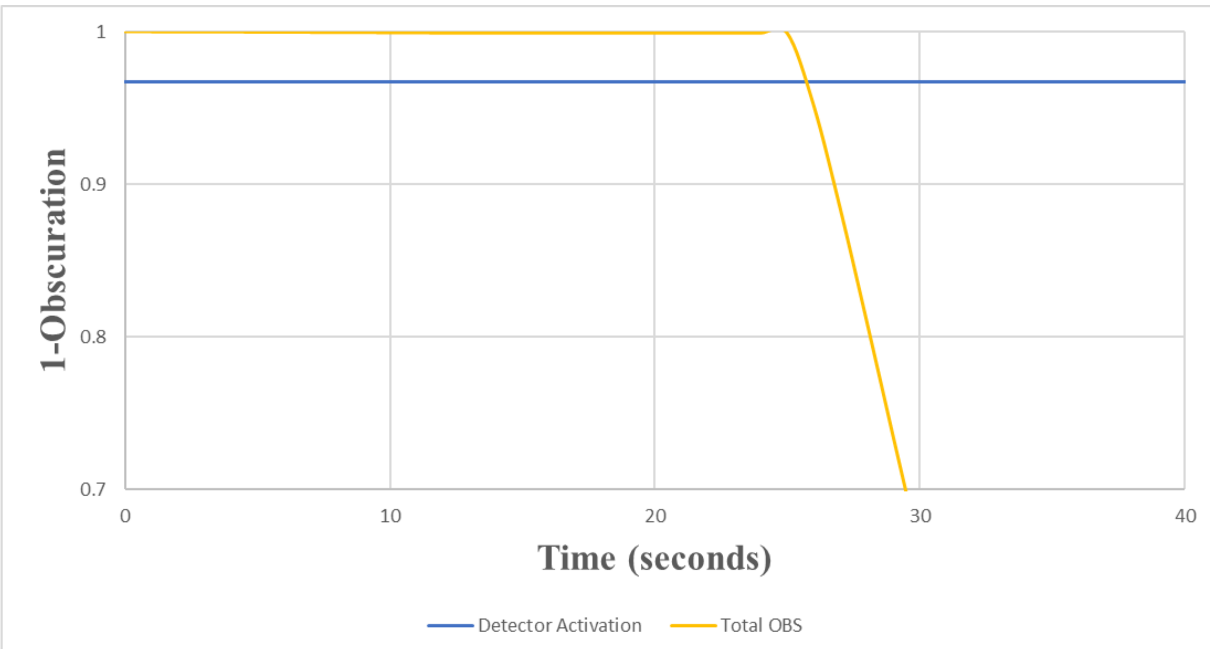


Figure 26- Time to Smoke Detector Activation

Once the doors close, stairwell #1 will become relatively clear as any smoke that flowed into the stairwell dissipates. This is misleading to the evacuating occupants of who some will attempt to egress via stairwell #1, becoming engulfed in smoke when they open the door. The confusion caused by the smoke and the loss of the primary means of egress could significantly delay the egress of occupants on the upper floors.

4.5.3. DESIGN FIRE SCENARIO 2

The fire in this scenario begins in the student lounge area of the library's third floor, near the documents stacks on the north side of the building. The area of the building where this fire occurs is not ventilation limited. The fire initiates when a cellphone overheats, igniting an upholstered chair, and soon propagates through the rest of the lounge area and to the nearby document stacks. This portion of the library has the largest area of proximate fuel packages. There are 10 upholstered chairs in the lounge area and 62 sets shelving units as described in Section 4.4 of this report. As the library is not sprinklered in this area, there will be nothing to limit the fire growth. Figure 27 shows the library stack area on the third floor of Kennedy Library; the location of the fire scenario is within the outlined area. Figure 28 shows the origin, fuel packages and area of fire spread on the third floor.

Figure 27- Third Floor Library Stack Area Layout on West Side of Kennedy Library

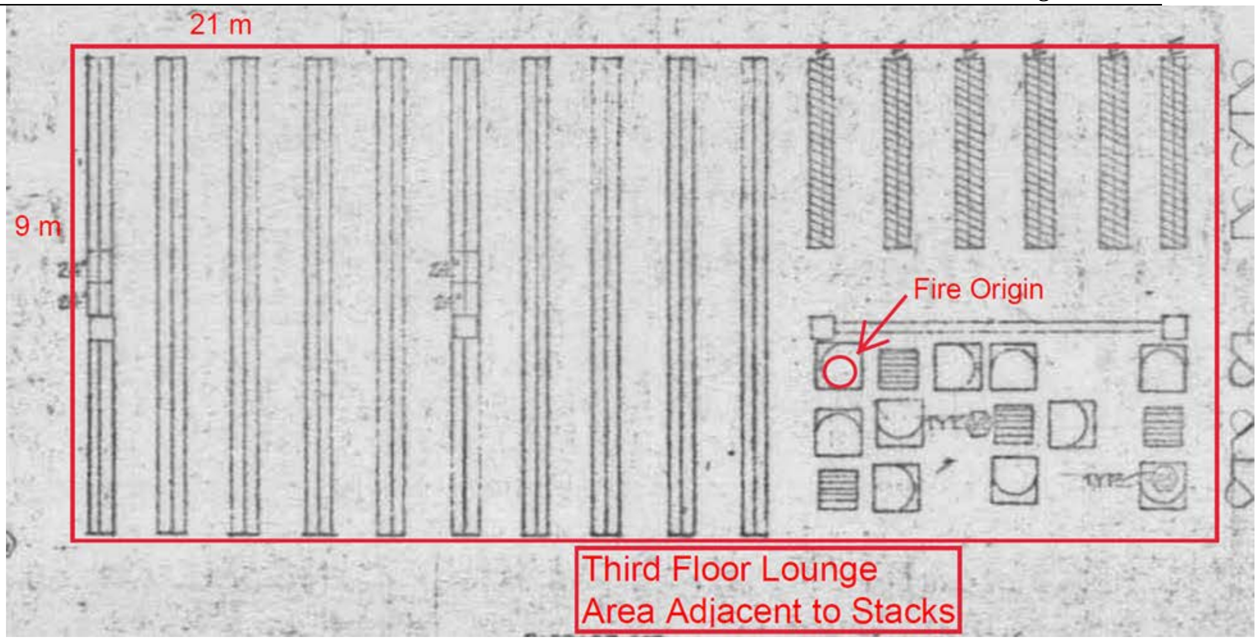


Figure 28- Kennedy Library, Third Floor Level Lounge and Document Stack Area

The upholstered chair ignites at time 0. The fire will continue to grow until it reaches its peak HRR as shown in Figure 18. The peak heat flux of the upholstered chair was measured to be 25 kW/m^2 at 1 meter. The critical heat flux of paper and wood materials is 10 kW/m^2. The upholstered chair is approximately 1 meter from the nearest shelving units, the heat flux from the chair is therefore more than sufficient to cause the ignition of the shelves. As the fire grows it will eventually emit a heat flux sufficient to ignite adjacent fuel packages. The fire will spread unabated as the area is not ventilation limited and there is no suppression in place. Adjacent fuel packages (upholstered chair or shelving unit) are assumed to ignite at 40 second intervals. The decay of the burning fuel packages has been modeled as a reflection of the growth curve. Any excess stored energy is expended in a steady peak HRR state. The HRR-time curve is shown in Figure 29.

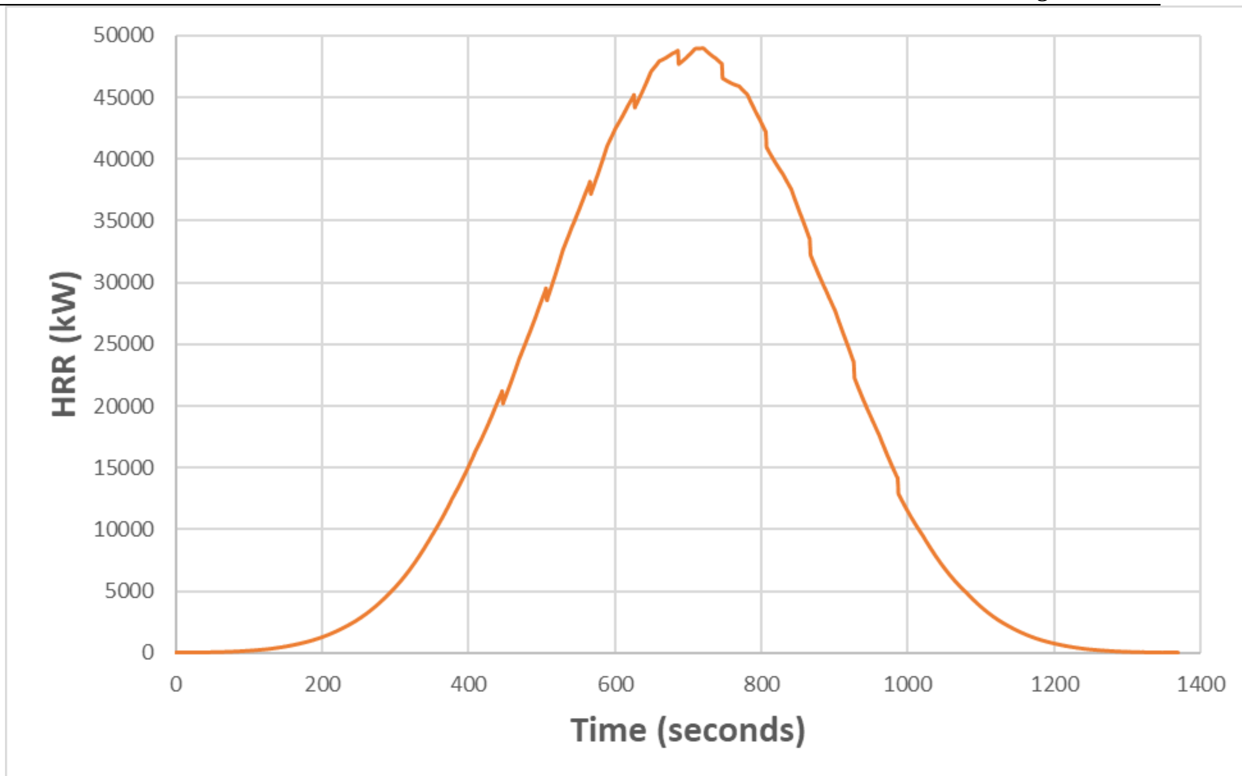


Figure 29- Fire Scenario 2 HRR-Time Curve

This fire is relatively slow, however, since there is no automatic method of detection in the area, the fire poses a risk to the occupants on other floor levels who may not be exposed to the smoke. Considering the amount of heat released and the amount of fuel available, this fire could potentially spread to other areas of the floor level and create an untenable situation for the entire floor level. It is assumed that an occupant on the floor level of the fire will activate a pull station which are installed at every exit, however, in the event that some occupants ignore the evacuation alarm they will be in great danger.

4.5.4. DESIGN FIRE SCENARIO 3

The fire in this scenario begins in the large group study room (room 200) on the southside of the second floor. The room dimensions are 16 x 7 m and the ceiling height is 3 m. The building experiences a power surge which results in a lightbulb shattering and showering sparks onto the rooms furnishings, igniting a chair. The fire continues to propagate until flashover occurs due to the room being ventilation limited. Both of the room's doors are open providing sources of oxygen. There is also mechanical ventilation with an assumed flow of 4 room changes per minute (0.45 kg of air per second). The power surge has also resulted in the malfunction of the fire alarm system which prevents the evacuation alarm from activating and consequently delaying occupant notification. Figure 30 shows the second-floor layout on the east side of of Kennedy Library; the location of the fire scenario is within the outlined area. Figure 31 shows the group study room (room 200), the fire origin and the surrounding area.

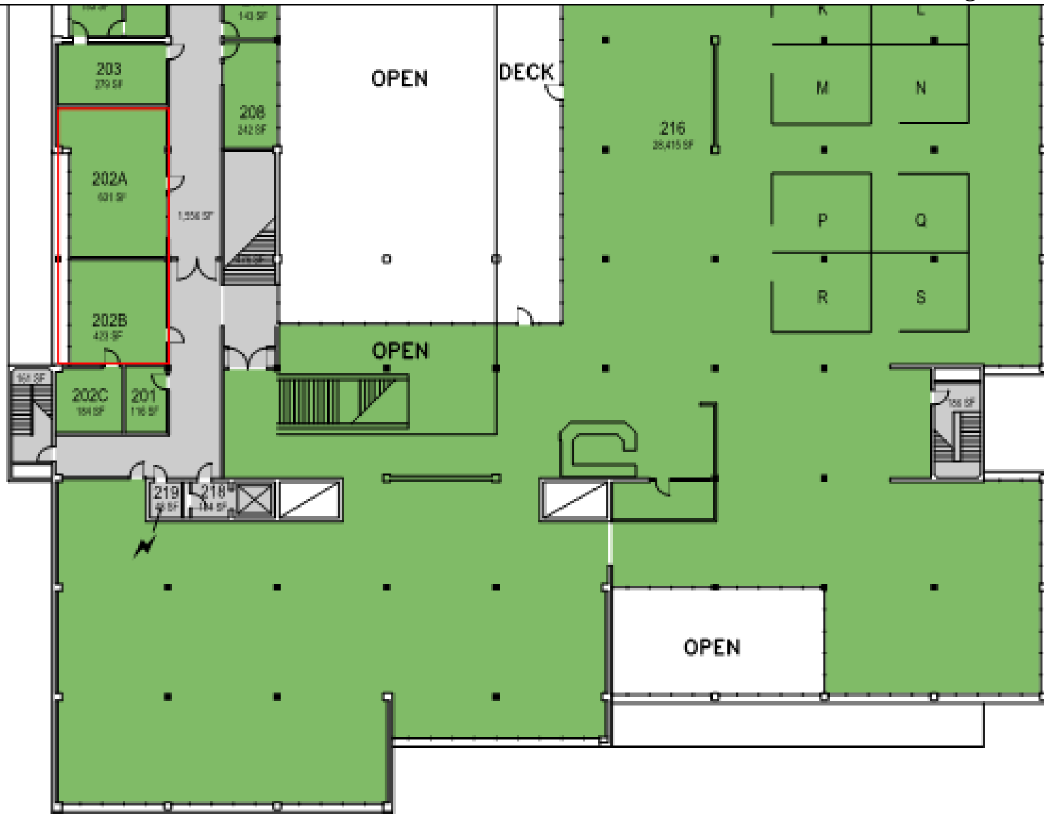


Figure 30- Second Floor Layout on East Side of Kennedy Library

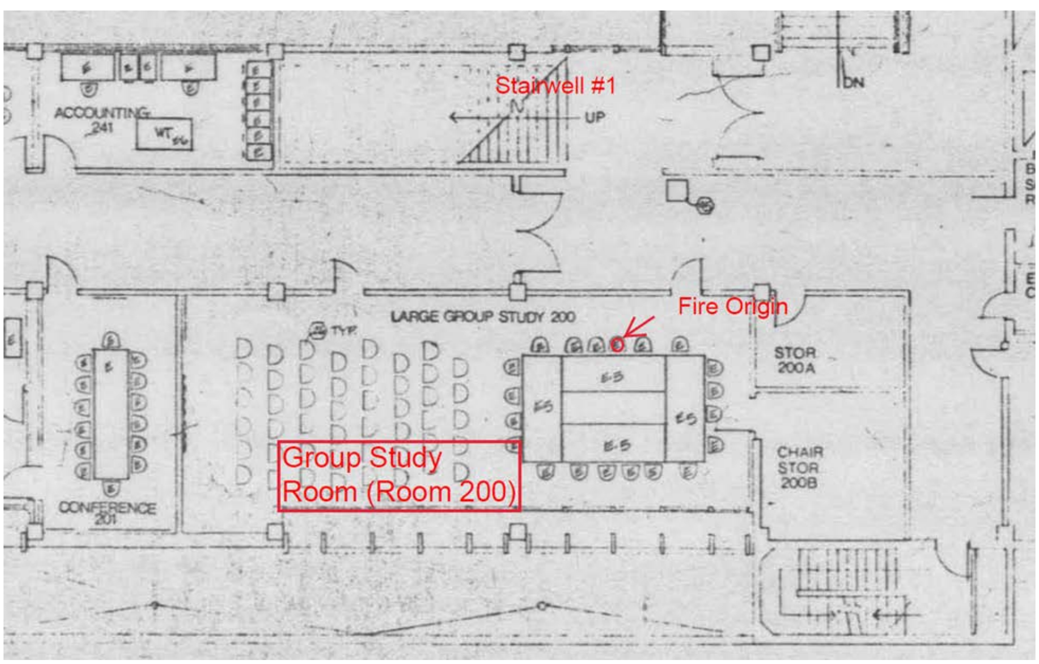


Figure 31- Kennedy Library, Second Floor Level Group Study Room

The first office chair ignites at time 0. The fire continues to grow, igniting the adjacent chairs until flashover occurs. Adjacent fuel packages (upholstered chair) are assumed to ignite at 40 second intervals. The decay of the burning fuel packages has been modeled as a reflection of the growth curve. Any excess stored energy in each chair is expended in a steady peak HRR state as shown in Figure 18. The HRR-time curve of 11 chairs is shown in Figure 32.

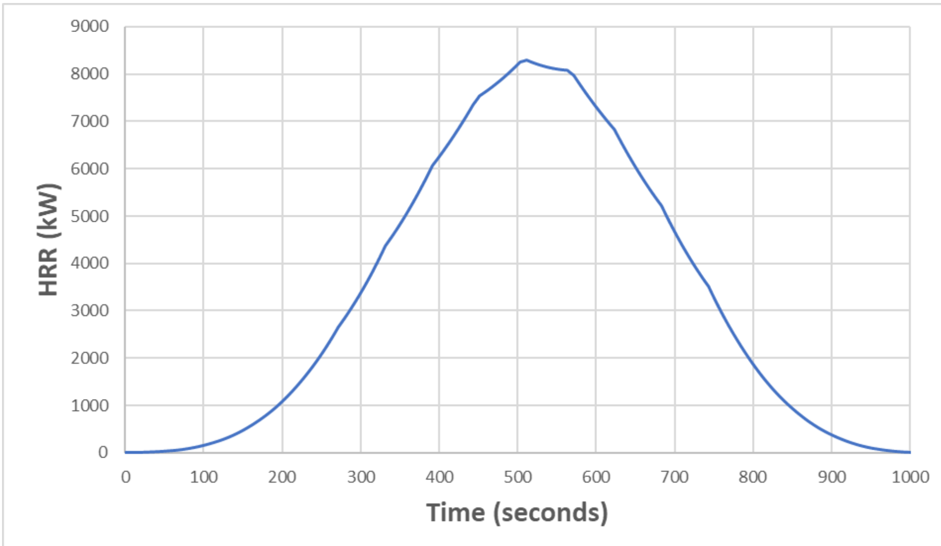


Figure 32- Fire Scenario 3 HRR-Time Curve

The compartment reaches flashover when the upper gas layer temperature reaches 500°C. The upper gas layer is calculated through the use of a two-zone model where the compartment is divided into two layers and each layer is assumed to have uniform conditions throughout. As the fire evolves, the upper layer grows and increases in temperature. The temperature increase is a result of heat being released and smoke accumulating below the ceiling. The mass of smoke in a smoke plume is negligible when compared to the mass of air that is being entrained, therefore, calculating the rate of air entrainment gives the rate of smoke accumulation. The rate of air entrainment is calculated using Equation 1 from the Zukoski method. The temperature of the upper layer is derived from the temperature of the smoke which is calculated using Equation 2.

The mass of smoke in the upper layer is simply calculated by multiplying $\dot{m}_a$ by the time step and adding the mass of smoke that is currently in the upper layer. The temperature of the upper layer is calculated using Equation 6, where Δt is the time step, m_{cv} is the mass of the control volume (upper layer) and T_U is the temperature of the upper layer.

$$\frac{\dot{m}_a T_s \Delta t + (m_{cv} T_U) i}{m_{cv,i+1}}$$ **Equation 6**

Using the HRR from the burning chairs, the upper layer temperature is calculated versus time giving the time to flashover (upper layer temperature of 500°C). The depth of the upper smoke layer is also calculated versus time. The upper layer temperature-time curve and the upper smoke layer depth-time curve are shown in Figure 33 and Figure 34.

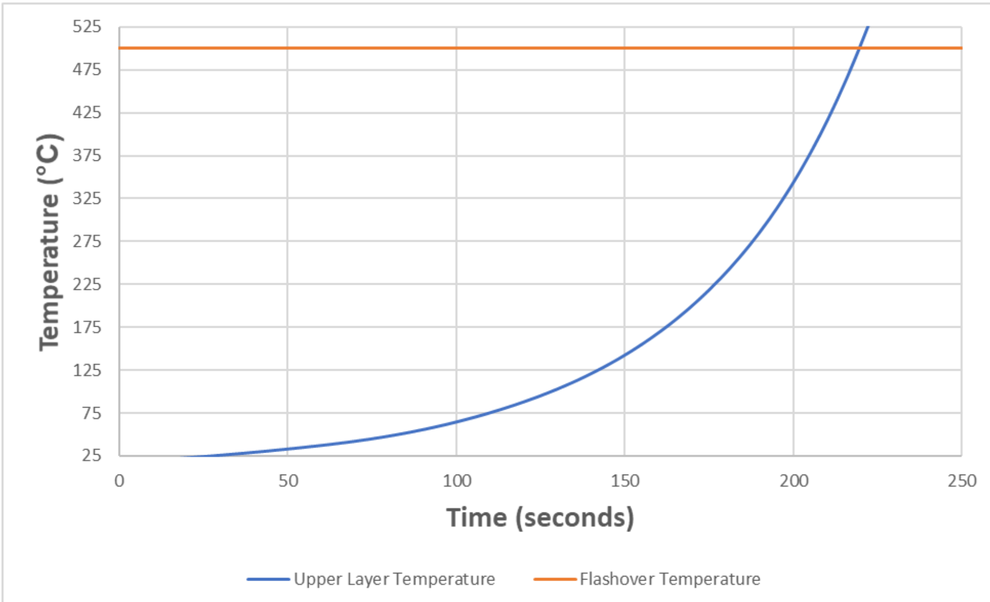


Figure 33- Upper Layer Temperature-Time Curve

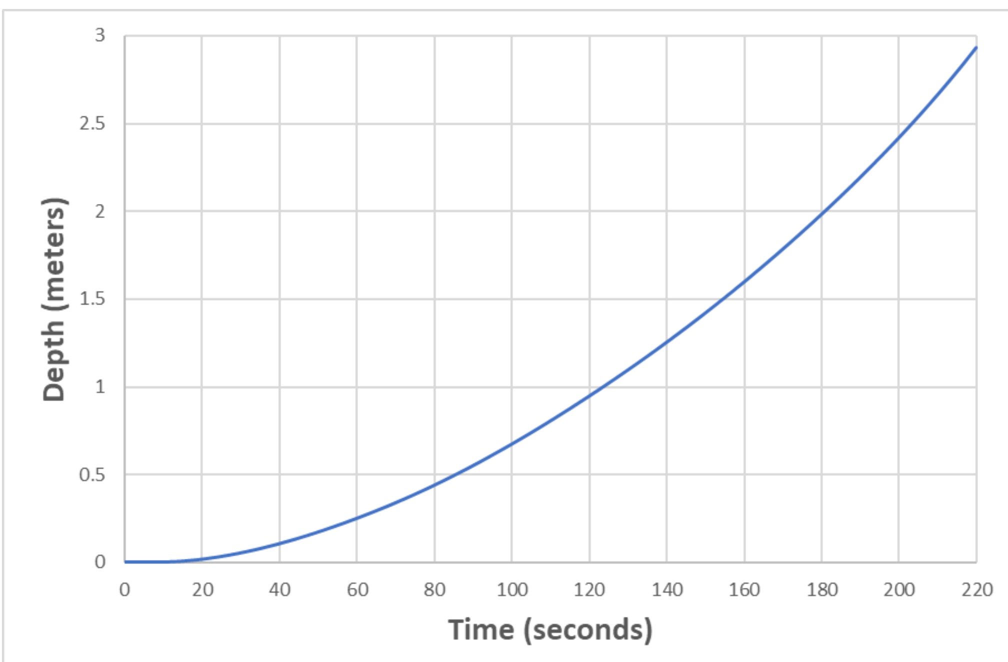


Figure 34- Upper Smoke Layer Depth-Time Curve

There is a storage closet in the group study room but other than what is stored in it, there are no fuel packages for the fire to spread to outside of the room. Once the room reaches flashover, an enormous amount of heat and smoke is being released into the corridor outside the room. The corridor will quickly become untenable, blocking one of the floors exits and potentially trapping occupants in other rooms on the corridor. With the fire alarm system being inoperable, the fire doors will not close and the smoke from the fire will enter the primary stairwell (stairwell #1) and travel up to the 5th floor level, thus eliminating access to the stairwell for the entire building. With the lack of automatic sprinklers and the inoperability of the automatic detection and notification, there is no active protection in place to reduce the risk that the occupants are exposed to.

4.5.5. MAIN FIRE SCENARIO

Design fire scenario 1 was chosen as the scenario to be analyzed with computer modeling. This scenario will have the most substantial impact on building evacuation due to the location being in the main entrance foyer and at the foot of the primary stairway.

4.6. COMPUTER MODEL

4.6.1. PERFORMANCE CRITERIA

The tenability criteria outlined in section 4.3 of this report is the performance criteria to be analyzed with the modeling. The results from the computer model will indicate whether the occupants will be able to evacuate prior to the environment in the building lobby becoming untenable.

4.6.2. SOFTWARE

The software that is used to model the fire scenario is FDS (Fire Dynamics Simulator)(version 6.7.0). FDS is a computational fluid dynamics software (CFD) which is design to calculate low-speed flows using Navier-Stokes methodology. Pyrosim was used to write the FDS code for the model. Pyrosim is graphical user interface tool for FDS which simplifies the code writing process for models.

FDS is developed by the National Institute of Standards and Technology and is available at no cost. Pyrosim is a third-party software developed by Thunderhead Engineering.

4.6.3. MODEL DESCRIPTION

The HRR and fire growth as determined in Section 4.5.2 of this report were used for the fire. The peak HRR is reached at 130 seconds and is maintained until 850 seconds. The model is designed so that the smoke can through the stairway 1 opening to the second floor. There is a smoke detector at the stairway 1 doorway on the second floor included in the design. Activation of this smoke detector will initiate the building evacuation. Temperature and visibility are calculated at a height of 6 feet above the floor through the use of slice files. Figure 35 shows the first level floor layout in Pyrosim.

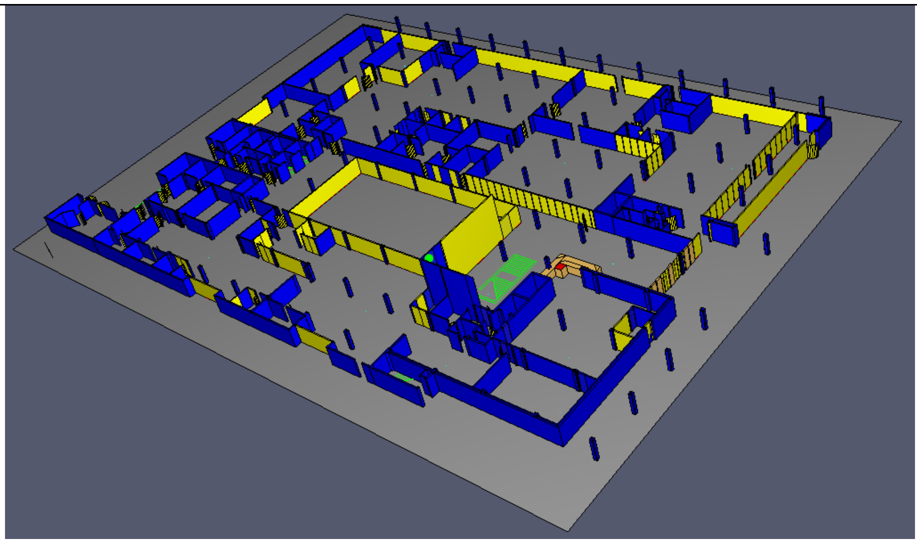


Figure 35- Kennedy Library First Floor Level Layout in Pyrosim

4.6.4. MODEL RESULTS

4.6.4.1. Detector Activation

The smoke detector is designed to activate at 3.28%/m obscuration using the Cleary Photoelectric smoke detector parameters. 3.28%/m obscuration occurs at approximately 70 seconds. Figure 36 shows the obscuration-time curve of the smoke detector. The 70 seconds to activation is significantly longer than the 26 seconds that was calculated in Section 4.5.2. The reason for this is that the simple calculation (Zukoski method) accounts for far fewer variables than FDS is able to account for. To account for smoke movement into other areas of the building using hand calculation methods would require many hours performing thousands of iterations.

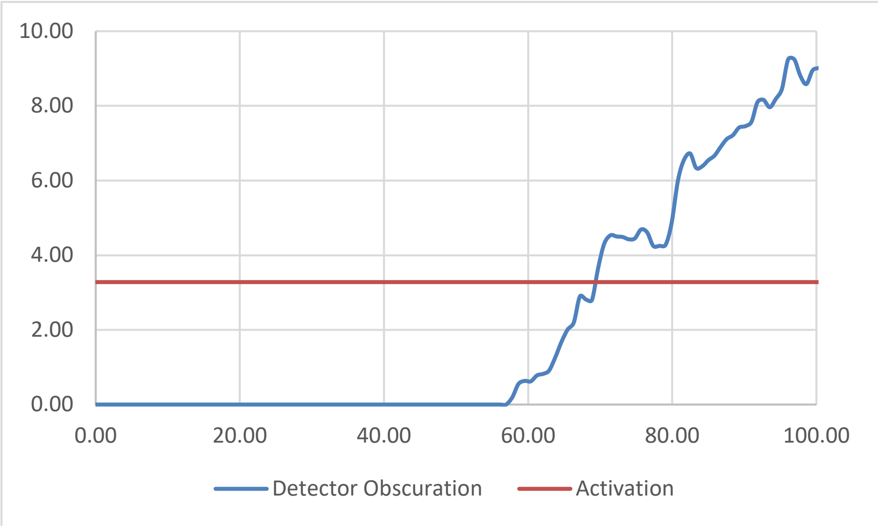


Figure 36- Obscuration-Time Curve of Smoke Detector

4.6.4.2. Visibility

The tenability criteria for visibility is 4 meters of visibility for occupants familiar with their environment and 13 meters for occupants who are not familiar.

Figure 37 shows the slice file from the model illustrating a reduction to 13 meters of visibility in the library foyer/circulation desk area occurs at approximately 190 seconds.

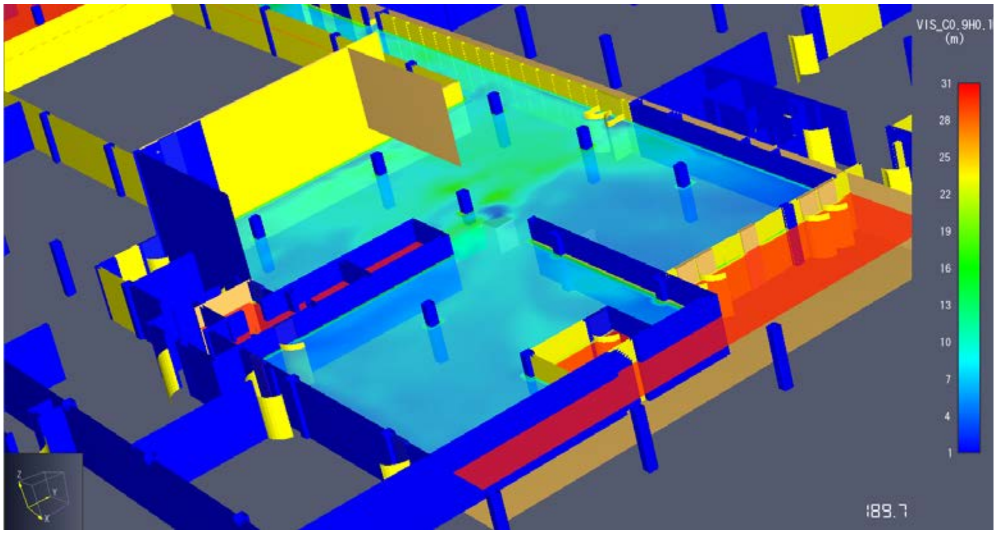


Figure 37- Slice File of Visibility Distance at 190 Seconds

Figure 38 shows the slice file from the model illustrating a reduction to 4 meters of visibility in the library foyer/circulation desk area occurs at approximately 500 seconds.

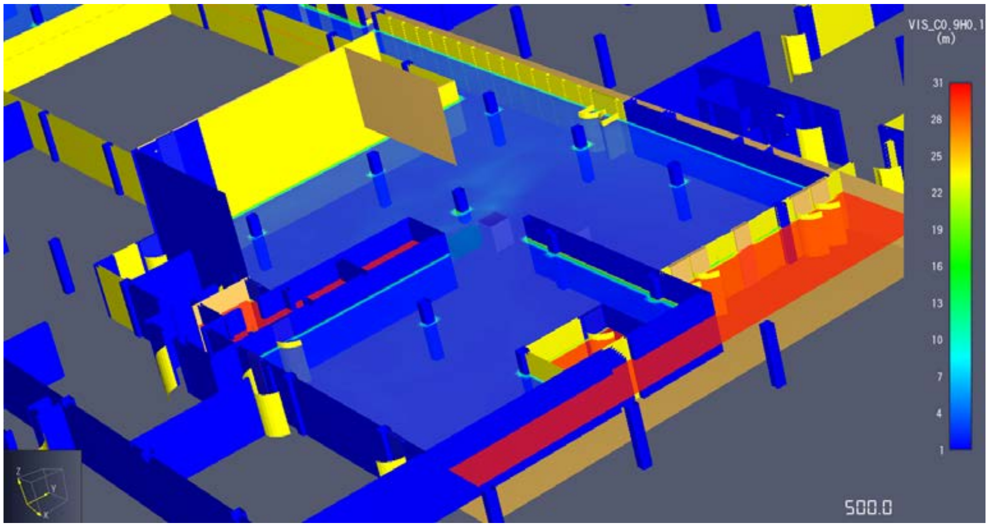


Figure 38- Slice File of Visibility Distance at 500 Seconds

4.6.4.3.Temperature

The tenability criteria for temperature is 80ºC for 15 minutes. At approximately 3 minutes, the temperature reaches 150ºC which is maintained until approximately 15 minutes from the start of the fire, when the fire, based on the fire test data, is expected to die out. Based on Figure 11, an exposure to 150ºC for more than 5 minutes is beyond human tolerance. The temperature within a few meters surrounding the fire is at a level that could cause immediate incapacitation (400 ºC +). Figure 39 shows the temperature at in the library's lobby at 800 seconds into the fire.

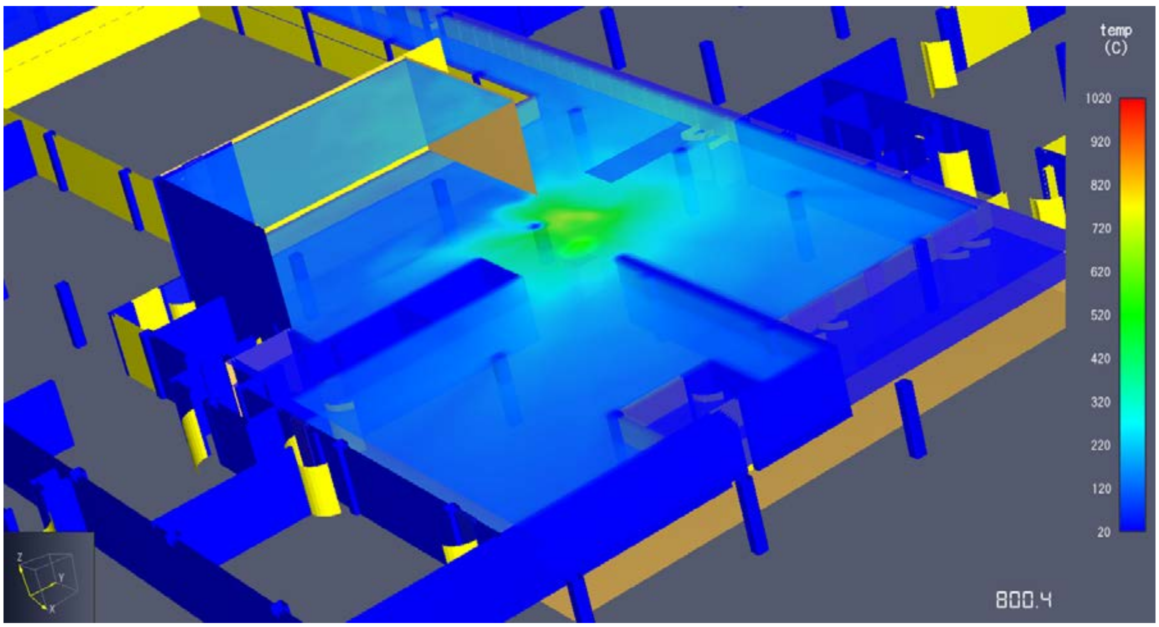


Figure 39- Slice File of Temperature at 800 Seconds

4.6.5. ANALYSIS OF MODEL RESULTS

The smoke detector is calculated to activate 70 seconds after ignition. Activation of the smoke detector prompts initiation of the building fire alarm which starts the evacuation (11 minutes as discussed in Section 4.2.4), beginning with pre-movement time (4 minutes as discussed in Section 4.2.2). Including the time to detector activation, the total RSET is 16 minutes.

The results for visibility reduction derived from the model provide a time to untenability for occupants unfamiliar with the build at 190 seconds and for occupants familiar with the building at 500 seconds. It can be expected that there will be occupants that are unfamiliar with the building present. The conditions in the foyer will become untenable prior the RSET being met, however, the availability of alternate means of egress means that occupants who approach the area of the fire can reroute to another exit once they have identified the untenable conditions there. As the untenable conditions expand, there will still be several exits available for an amount of time greatly exceeding the RSET.

The results of the temperature increase produced by the model show that the general conditions in the foyer are tenable for the first few minutes of evacuation, however, the fire is located such that exiting through the main building entrance would require passing by the fire where the conditions are untenable and could potentially result in immediate incapacitation. Similar to the results for visibility reduction, the availability of alternate means of egress means that occupants who approach the area of the fire can reroute to another exit once they have identified the hazardous conditions there.

5.0 CONCLUSIONS AND RECOMMENDATIONS

This analysis was performed based on applicable codes and standards. The structural features and fire exposure were analyzed per the IBC(1). The fire alarm system was analyzed per NFPA 72(6), a partial sprinkler system was designed per NFPA 13(3), the standpipe system was analyzed per NFPA 14(4). The life safety and passive fire protection features were analyzed per NFPA 101(8). This report does not analyze whether Kennedy Library is made in accordance with its CoR. There are three deficiencies and one potential deficient condition resulting from the prescriptive analysis. Two of the issues are related to the fire alarm system notification configuration. One deficiency is that the visual notification coverage is not in accordance with the IBC(1) or NFPA 101. The potential deficiency is that the audible notification coverage may not be in accordance with NFPA 101(8). The second identified deficiency is the incorrect door leaf swing direction of the doors that serve the inner courtyard on the first floor.

Aside from the identified deficiencies, the life safety features of Kennedy Library are more than adequate. The structure is very robust and is likely to maintain its integrity if the event of a fire but the with the large fire load, the consequences of an uncontrolled fire could result in the building becoming uninhabitable.

The performance-based analysis was developed based on guidance from NFPA 101(8) and criteria available in the SFPE Handbook(11). The RSET of 16 minutes that was determined is based on hydraulic flow calculations, time to detection and notification, and estimated pre-movement time. The ASET is based on the when the environment becomes untenable and building occupants are no longer able to evacuate. The ASET was determined through the development of fire scenarios and subsequent computer modeling of Design Fire Scenario 1 from Section 4.5.2. Three fire scenarios were originally developed to evaluate the adequacy of the fire protection features in different areas of the building. Design Fire Scenario 1 was determined to be the greatest hazard and was chosen for analysis using computer-based modeling The results of the computer model for Design Fire Scenario 1 show that the ASET, for all of the tenability criteria evaluated, is less than the RSET. This means that occupants will not be able to evacuate through the main building entrance/exit. However, there is adequate means of egress on the first-floor level for the first-floor occupants, without the availability of the main entrance and the main entrance is not a required means of egress for the second thru fifth floor levels.

The results of these analyses prompt the following recommendations:

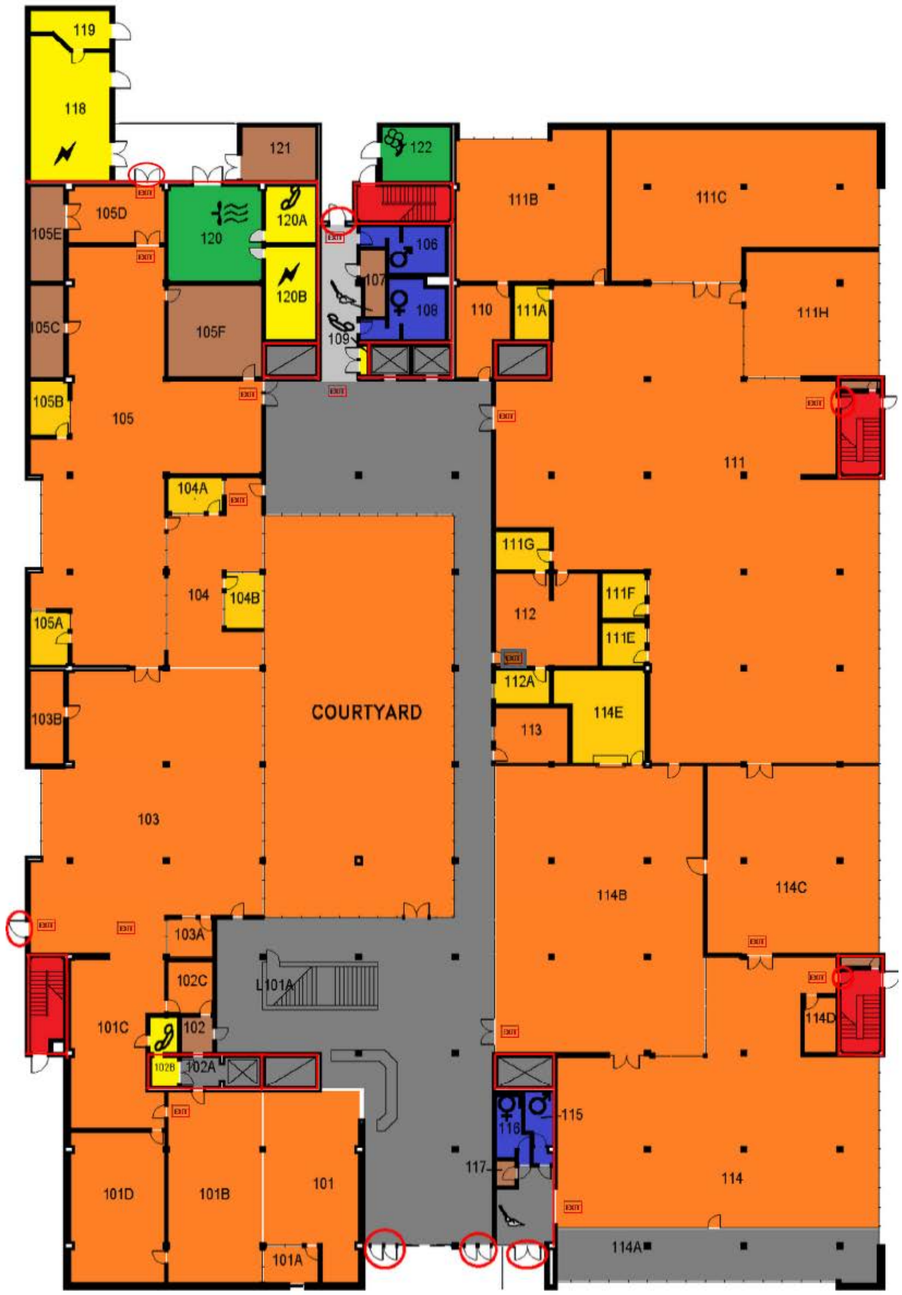
1. A detailed analysis of the adequacy of the visual notification coverage followed by the installation of additional notification devices where needed.
2. A sound level survey be performed throughout the building to determine the adequacy of the occupant notification portion of the fire alarm system.
3. Reverse the swing direct of the door leaves in the means of egress serving the inner courtyard.
4. Installation of an automatic sprinkler system throughout the building. A system is not required and may not be warranted when only considering life safety but the value of the contents and the continued operation of the facility, plus the benefits to life safety may make the cost of installing a system worthwhile.

6.0 REFERENCES

1. International Building Code, 2015
2. NFPA 10, *Standard for Portable Fire Extinguishers*, 2013 Edition
3. NFPA 13, *Standard for the Installation of Sprinkler Systems*, 2016 Edition
4. NFPA 14, *Standard for the Installation of Standpipe and Hose Systems,* 2016 Edition
5. NFPA 25, *Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems,* 2014 Edition
6. NFPA 72, *National Fire Alarm and Signaling Code*, 2016 Edition
7. NFPA 90A, *Standard for the Installation of Air-Conditioning and Ventilating Systems*, 2015 Edition
8. NFPA 101, *Life Safety Code*, 2015
9. NFPA 701, *Standard Methods of Fire Tests for Flame Propagation of Textiles and Films*, 2015 Edition
10. NFPA Fire Protection Handbook, 20th Edition
11. Society of Fire Protection Engineers. (2016). SFPE Fire Protecting Engineering Handbook, 5th Ed. New York: Springer.
12. ASTM D 2859, Standard Test Method for Ignition Characteristics of Finished Textile Floor Covering Materials, 2009 (2011)
13. ASTM E 84, Standard Test Method for Surface Burning Characteristics of Building Materials, 2013
14. ASTM E 119, Standard Test Methods for Fire Tests of Building Construction and Materials, 2012a
15. ANSI/UL 723, Standard for Test for Surface Burning Characteristics of Building Materials, 2008, Revised 2010.
16. Madrzykowski, D., & Kerber, S. (2009). Fire Fighting Tactics under Wind Driven Conditions: Laboratory Experiments. National Institute of Standards and Technology, TN 1618.
17. Walton, W. D., & Budnick, E. K. (1988). Quick Response Sprinklers in Office Configurations: Fire Test Results. National Bureau of Standards.
18. Sundstrom, B. (1995). Fire Safety of Upholstered Furniture--The Final Report on the CBUF Research (Report EUR 16477 EN). London: Interscience Communications Ltd.

7.0 ATTACHMENTS

7.1. ATTACHMENT 1 - KENNEDY LIBRARY FLOOR PLANS



Occupancy			
Occupancy Use	Load Factor	Area	Occupant Load
Assembly- Library Stack	100	23,049	230
Assembly - Library Reading Rooms	50 net	26,095	522
Business	100	1,337	14

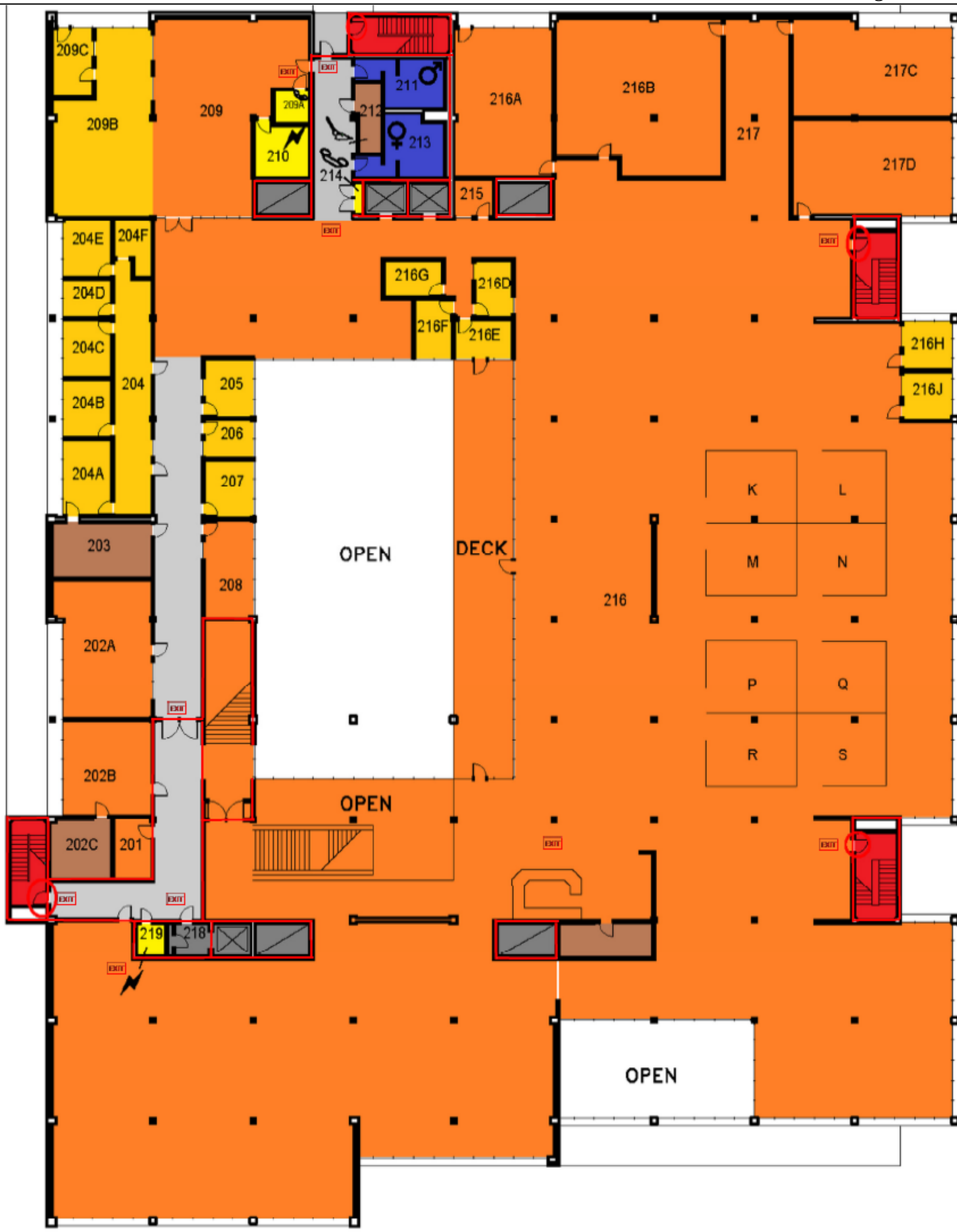
Robert E. Kennedy Library

Egress	
Egress Capacity	2,160
No. of Exits Req.	3

2-Hour Fire Wall

Floor 1

Space Designation	Color Codes
Assembly	
Business	
Storage	
Mechanical Rooms	
Electrical Rooms	
Restrooms	
Elevators and lobbies	
Exit Corridors	
Exit stairs	



Occupancy			
Occupancy Use	Load Factor	Area	Occupant Load
Assembly- Library Stack	100	35,901	359
Assembly - Library Reading Rooms	50 net	7,255	146
Assembly- Less concentrated use without fixed seating	15 net	241	17
Business	100	3,234	33

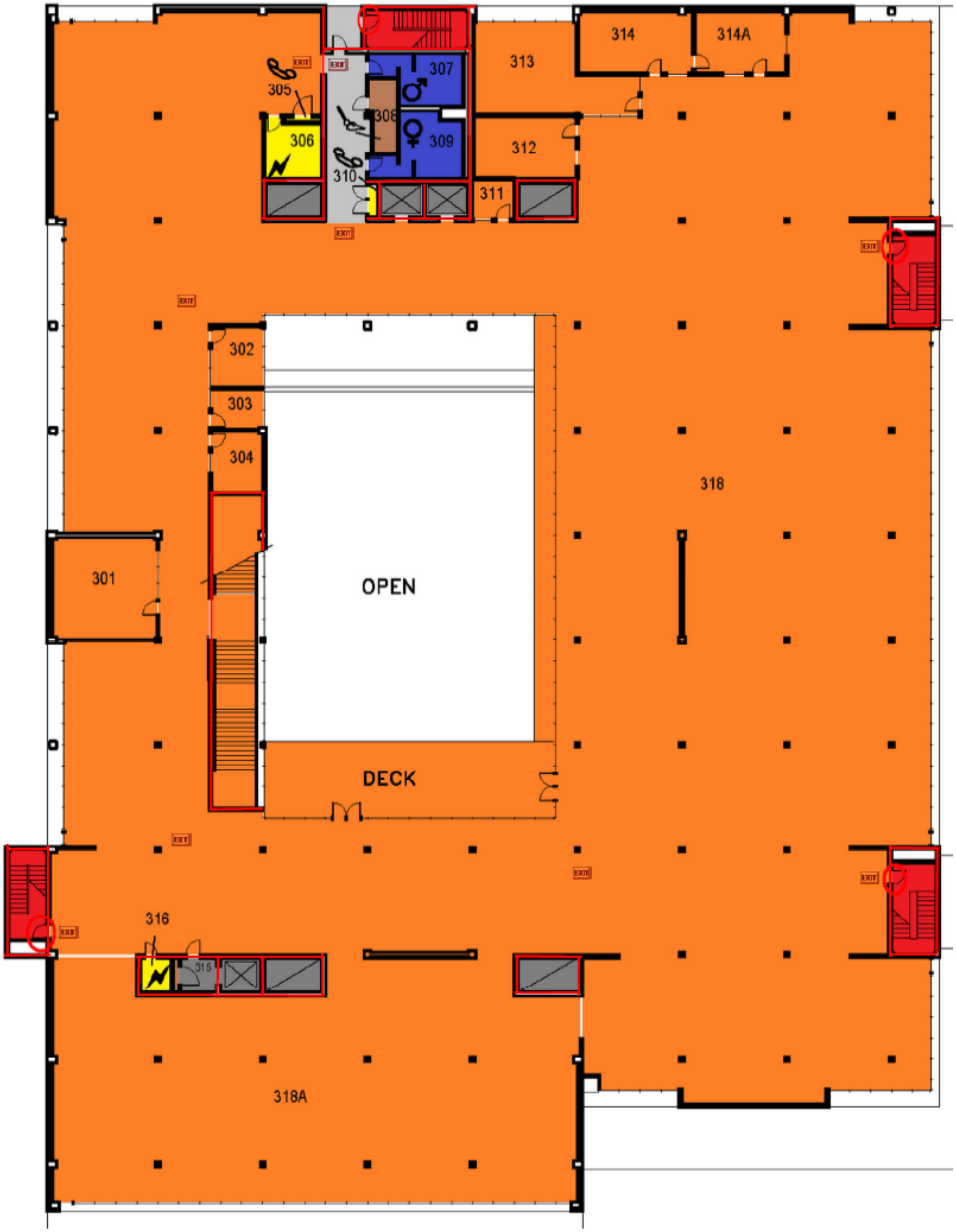
Robert E. Kennedy Library

Egress	
Egress Capacity	660
No. of Exits Req.	3

2-Hour Fire Wall

Floor 2

Space Designation	Color Codes
Assembly	
Business	
Storage	
Mechanical Rooms	
Electrical Rooms	
Restrooms	
Elevators and lobbies	
Exit Corridors	
Exit stairs	



Occupancy			
Occupancy Use	Load Factor	Area	Occupant Load
Assembly- Library Stack/ Business	100	38,675	387
Assembly - Library Reading Rooms	50 net	2,631	53
Assembly- Less concentrated use without fixed seating	15 net	289	20

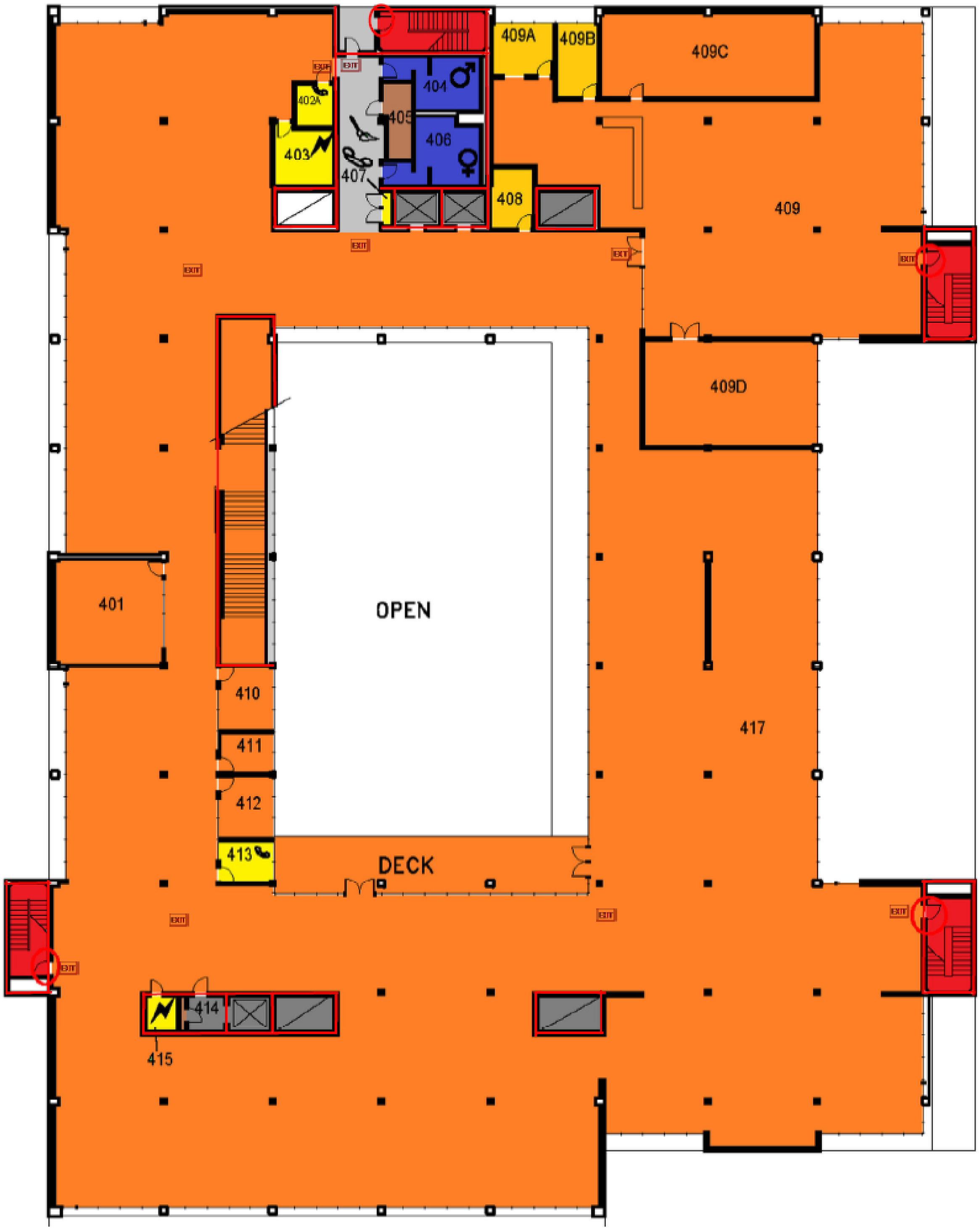
Robert E. Kennedy Library

Egress	
Egress Capacity	660
No. of Exits Req.	2

2-Hour Fire Wall

Floor 3

Space Designation	Color Codes
Assembly	
Business	
Storage	
Mechanical Rooms	
Electrical Rooms	
Restrooms	
Elevators and lobbies	
Exit Corridors	
Exit stairs	



Occupancy			
Occupancy Use	Load Factor	Area	Occupant Load
Assembly- Library Stack/ Business	100	32,772	328
Assembly - Library Reading Rooms	50 net	2,437	49
Business	100	377	4

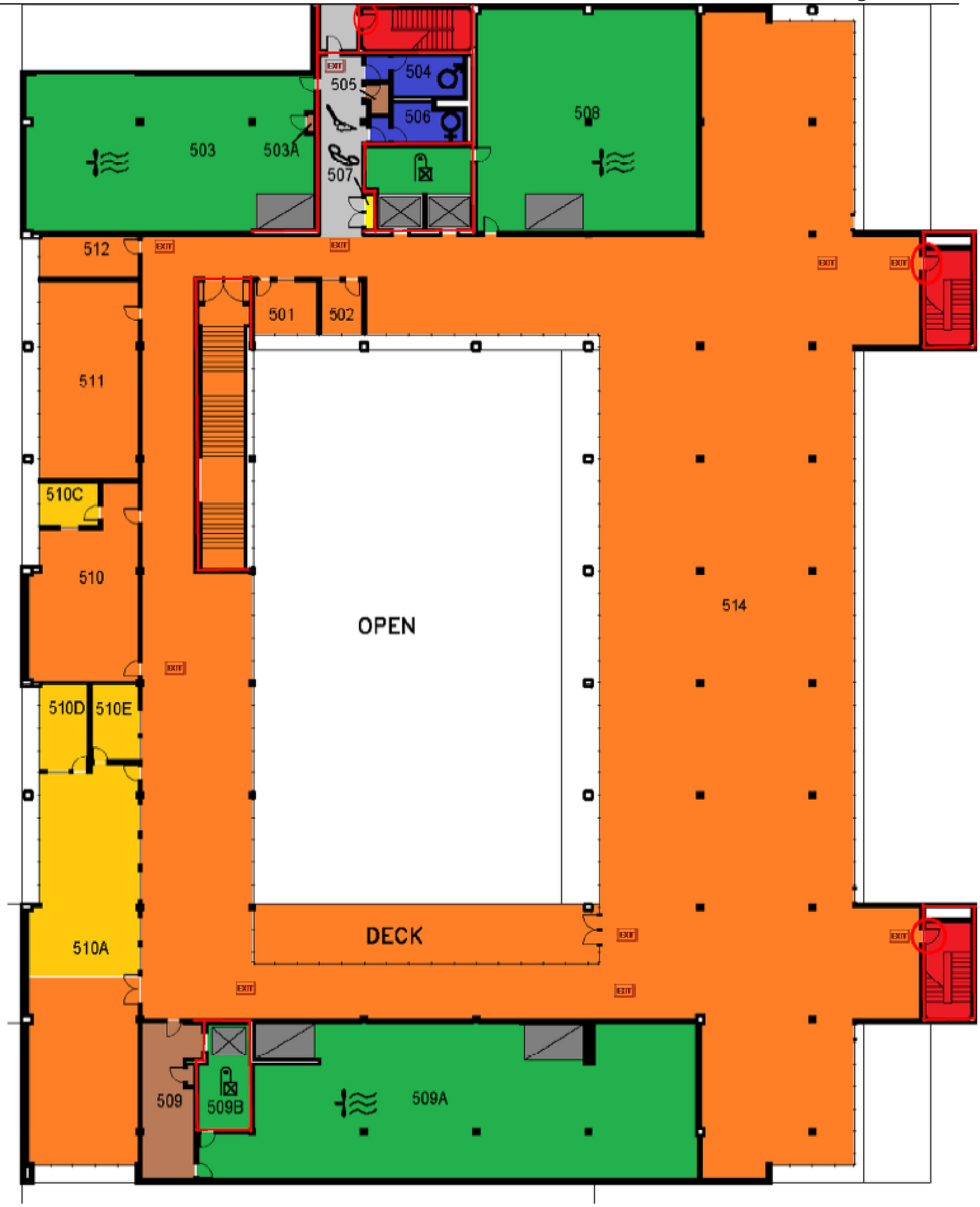
Robert E. Kennedy Library

Egress	
Egress Capacity	660
No. of Exits Req.	2

2-Hour Fire Wall

Floor 4

Space Designation	Color Codes
Assembly	
Business	
Storage	
Mechanical Rooms	
Electrical Rooms	
Restrooms	
Elevators and lobbies	
Exit Corridors	
Exit stairs	



Occupancy			
Occupancy Use	Load Factor	Area	Occupant Load
Assembly- Library Stack/ Business	100	28,354	283
Assembly - Library Reading Rooms	50 net	3,702	74
Business	100	2,116	21

Robert E. Kennedy Library

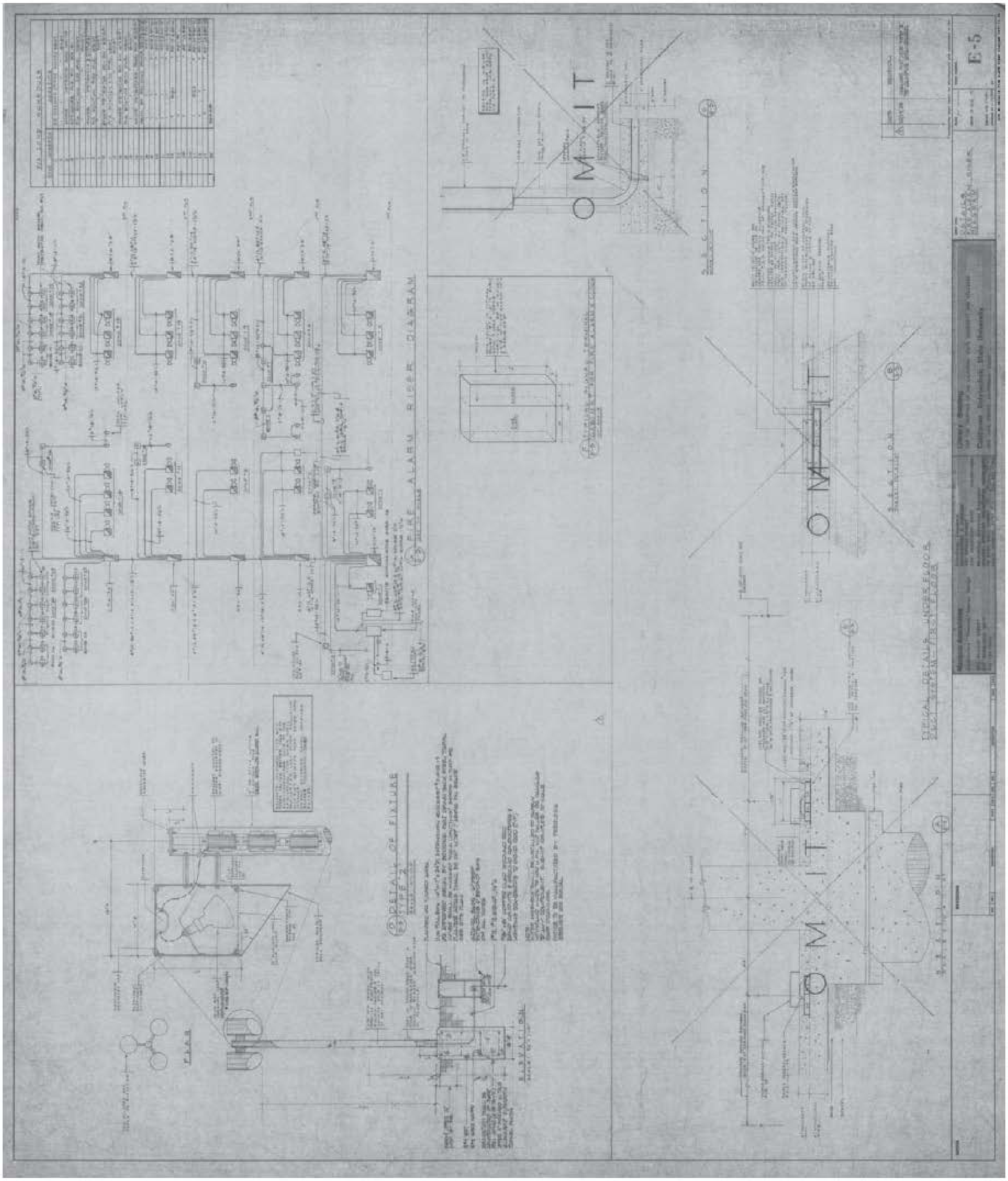
Egress	
Egress Capacity	495
No. of Exits Req.	2

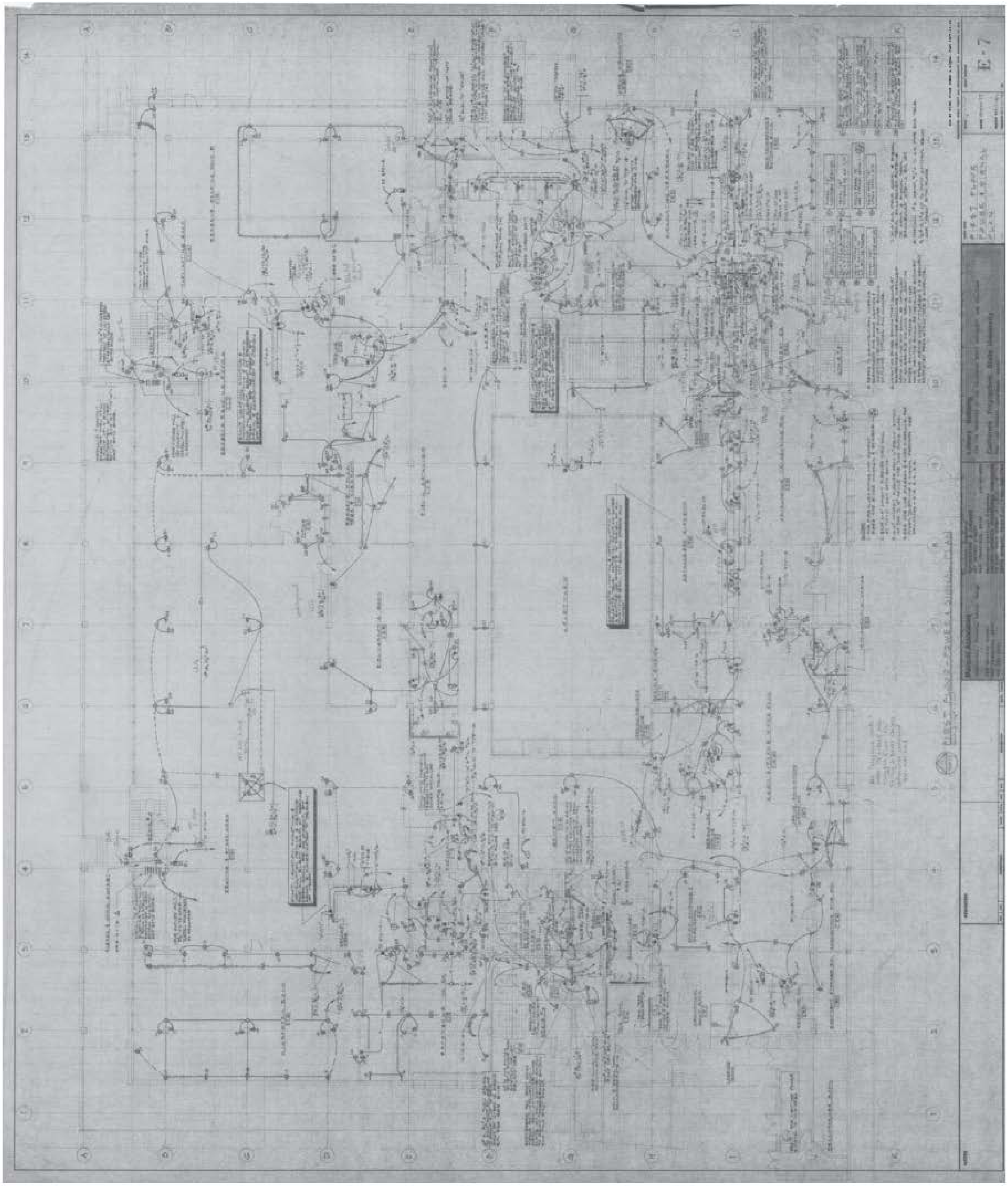
2-Hour Fire Wall

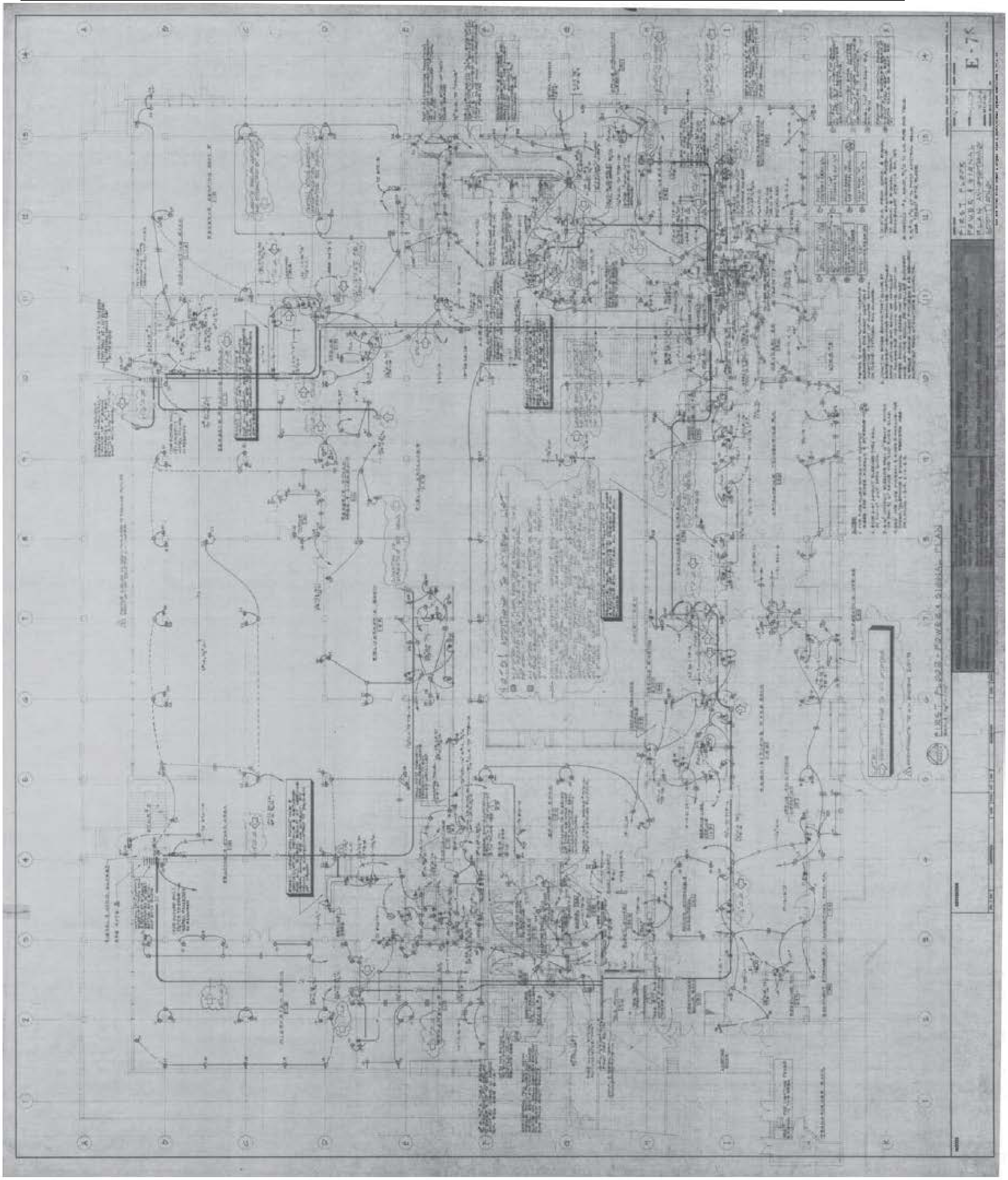
Floor 5

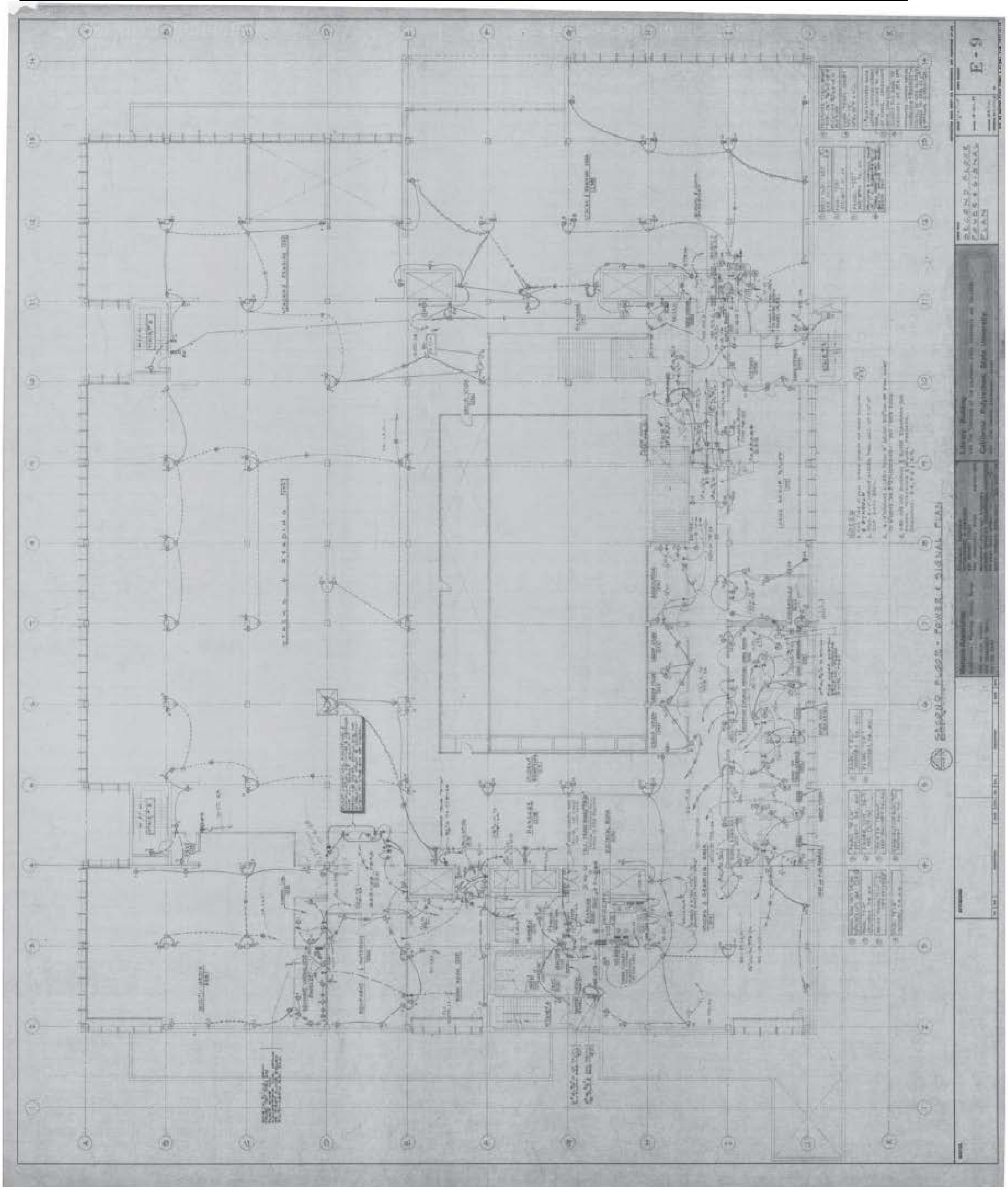
Space Designation	Color Codes
Assembly	
Business	
Storage	
Mechanical Rooms	
Electrical Rooms	
Restrooms	
Elevators and lobbies	
Exit Corridors	
Exit stairs	

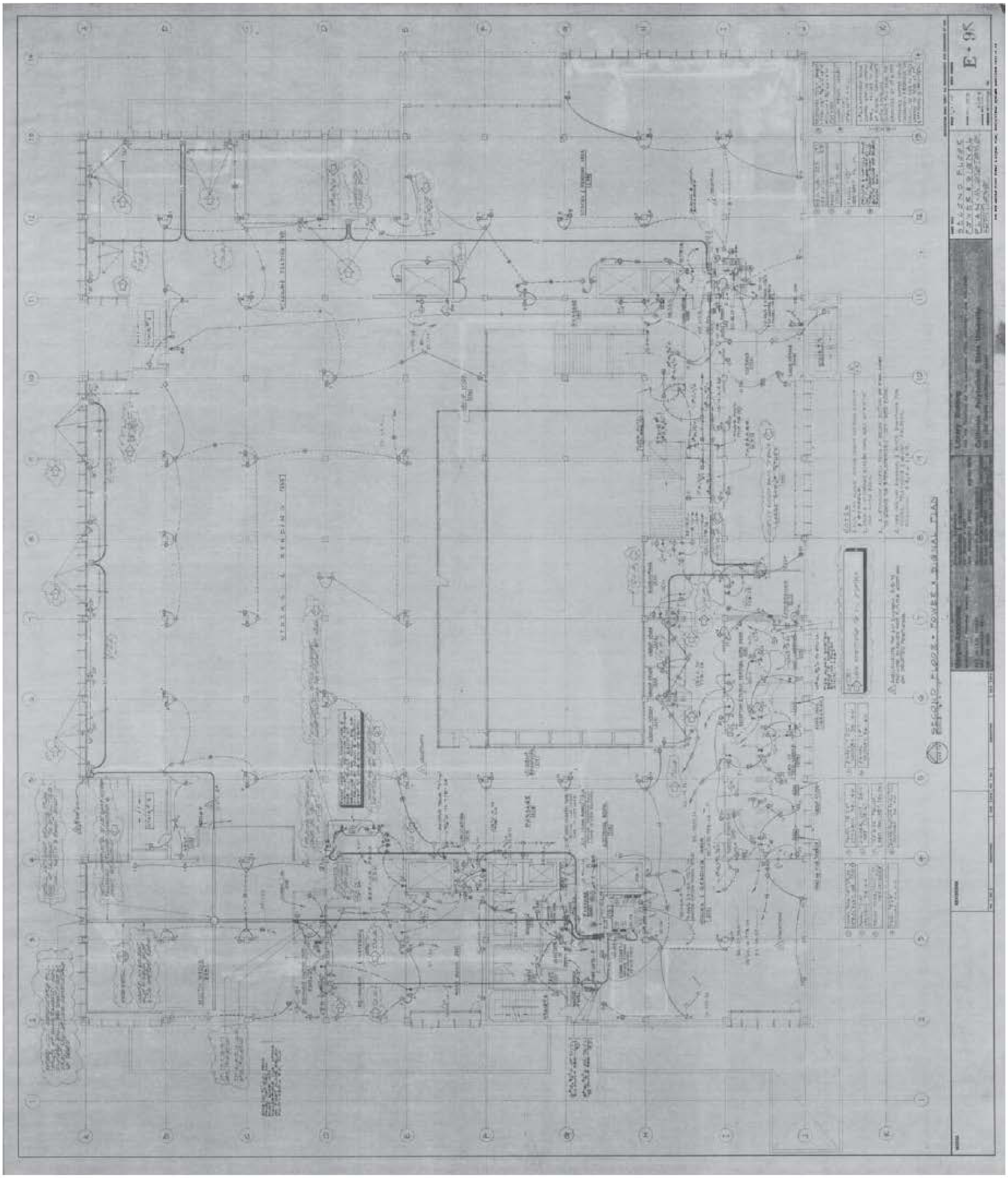
7.2. ATTACHMENT 2 - FIRE ALARM SYSTEM DRAWINGS

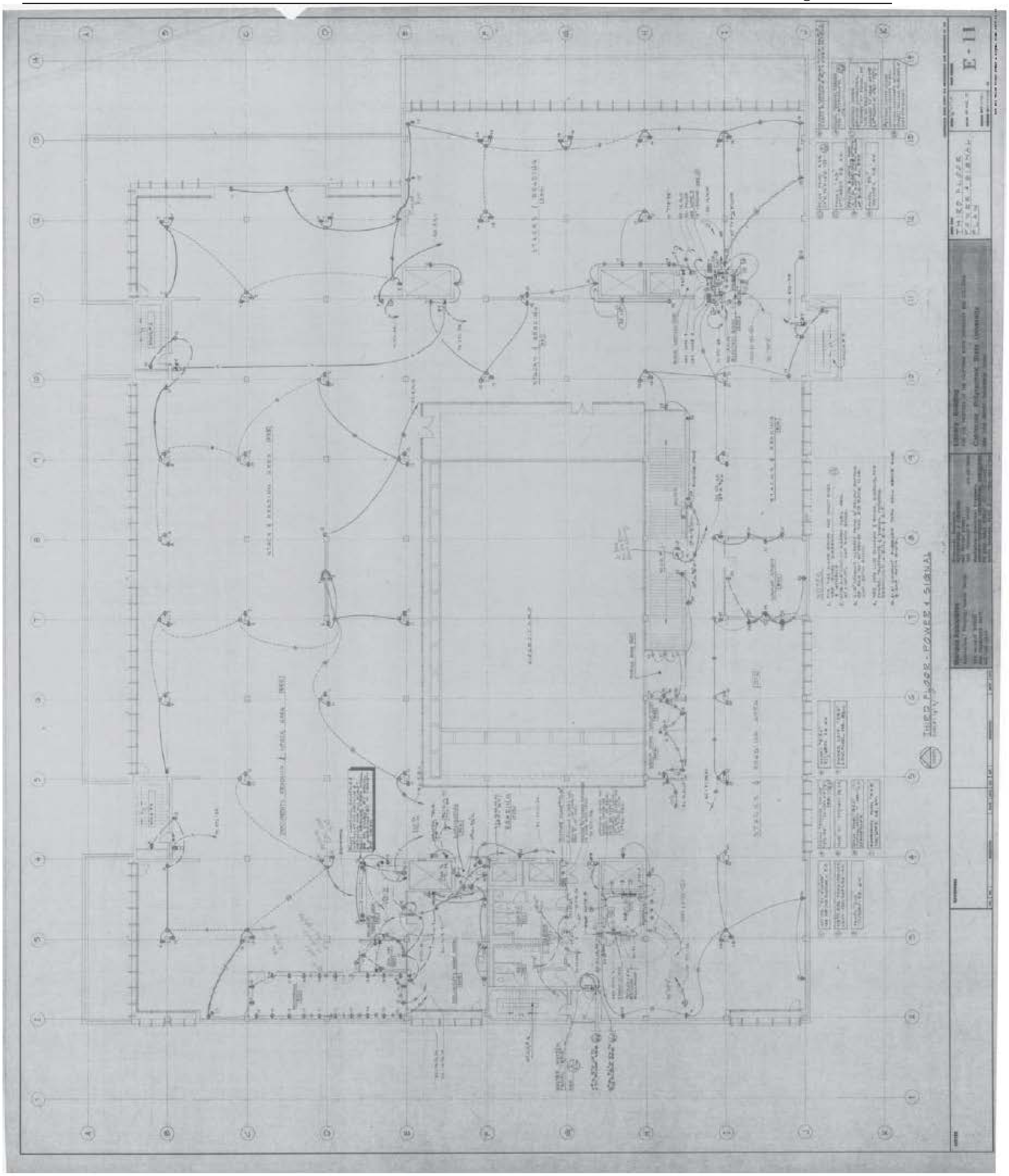


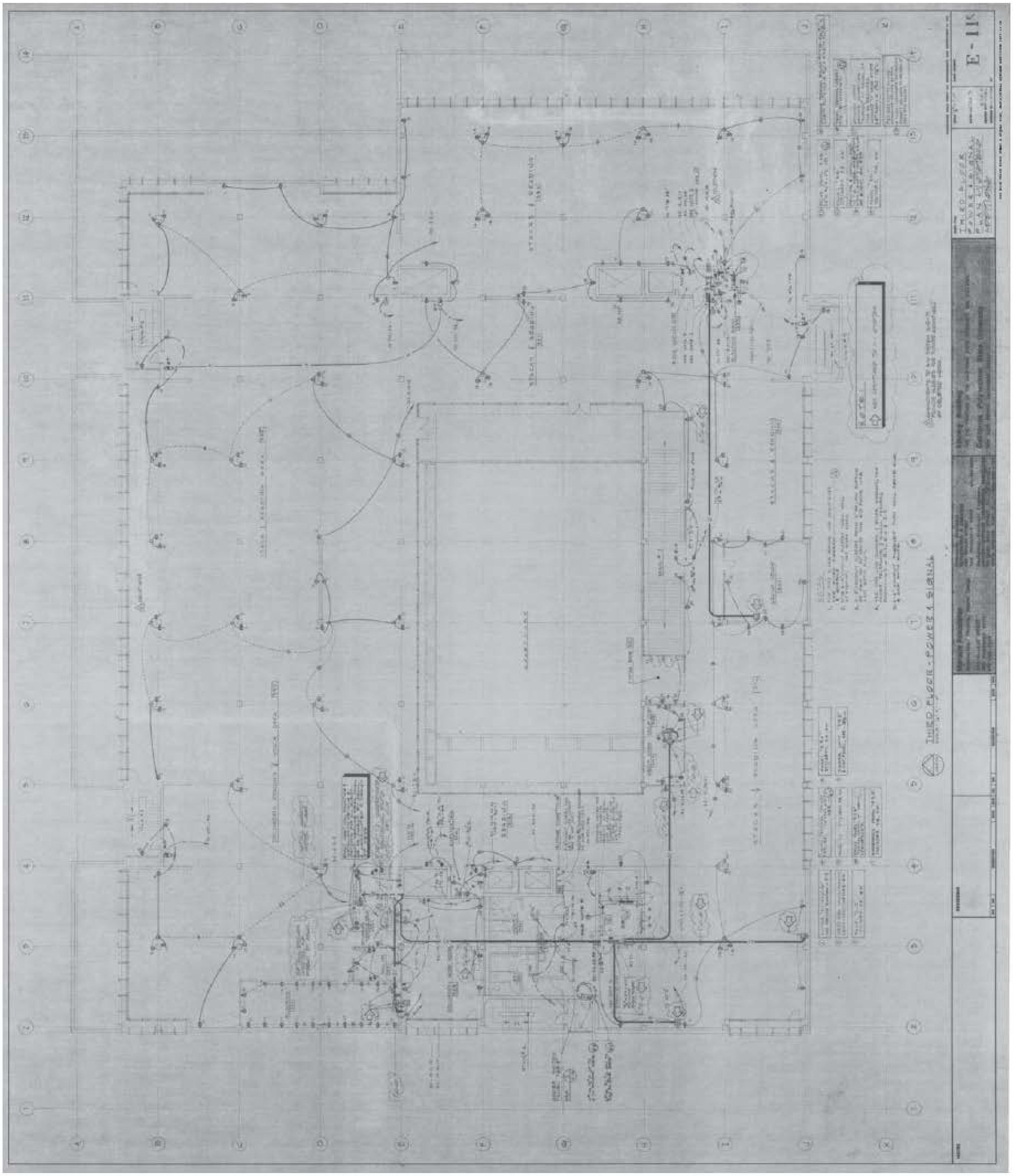


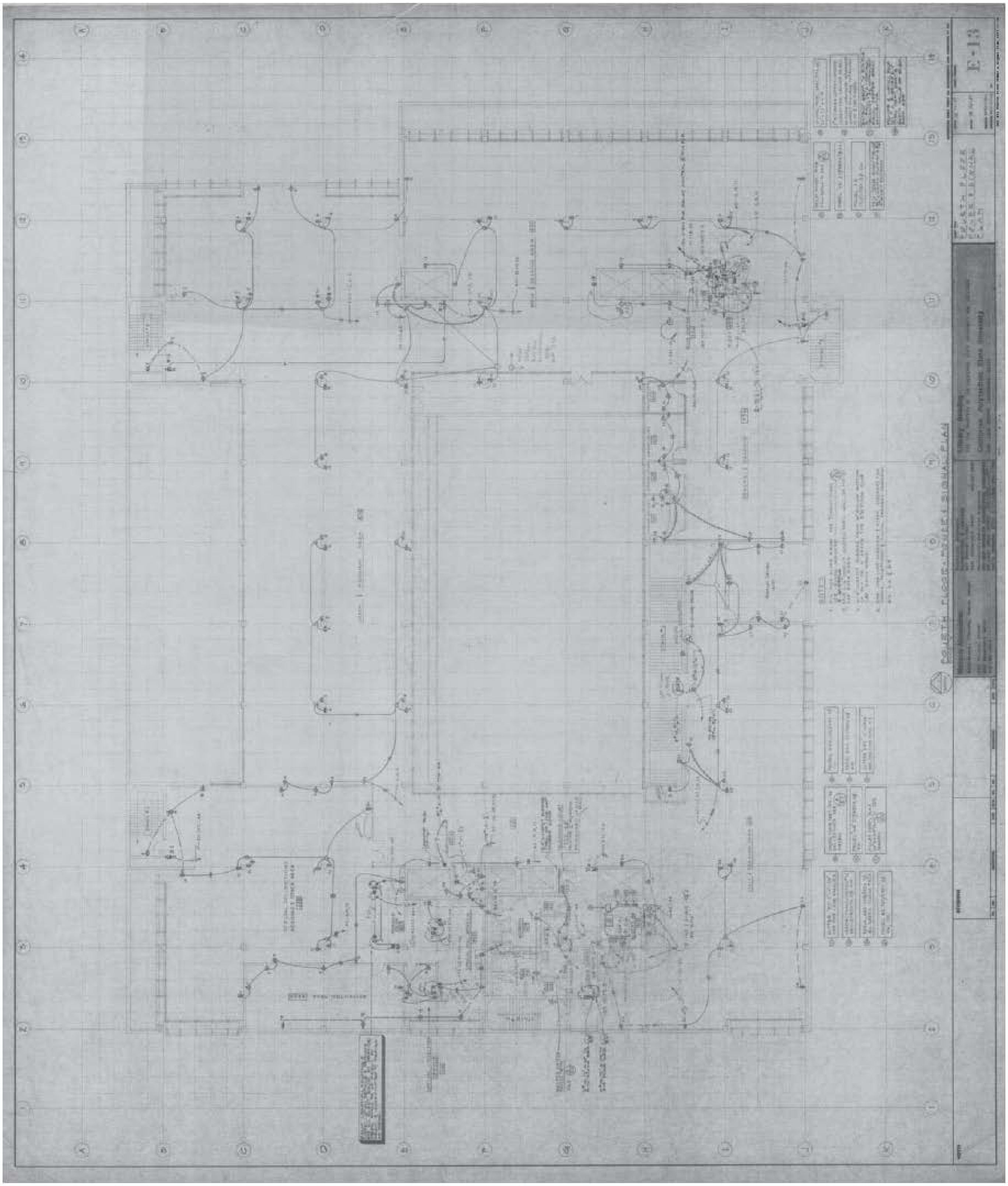


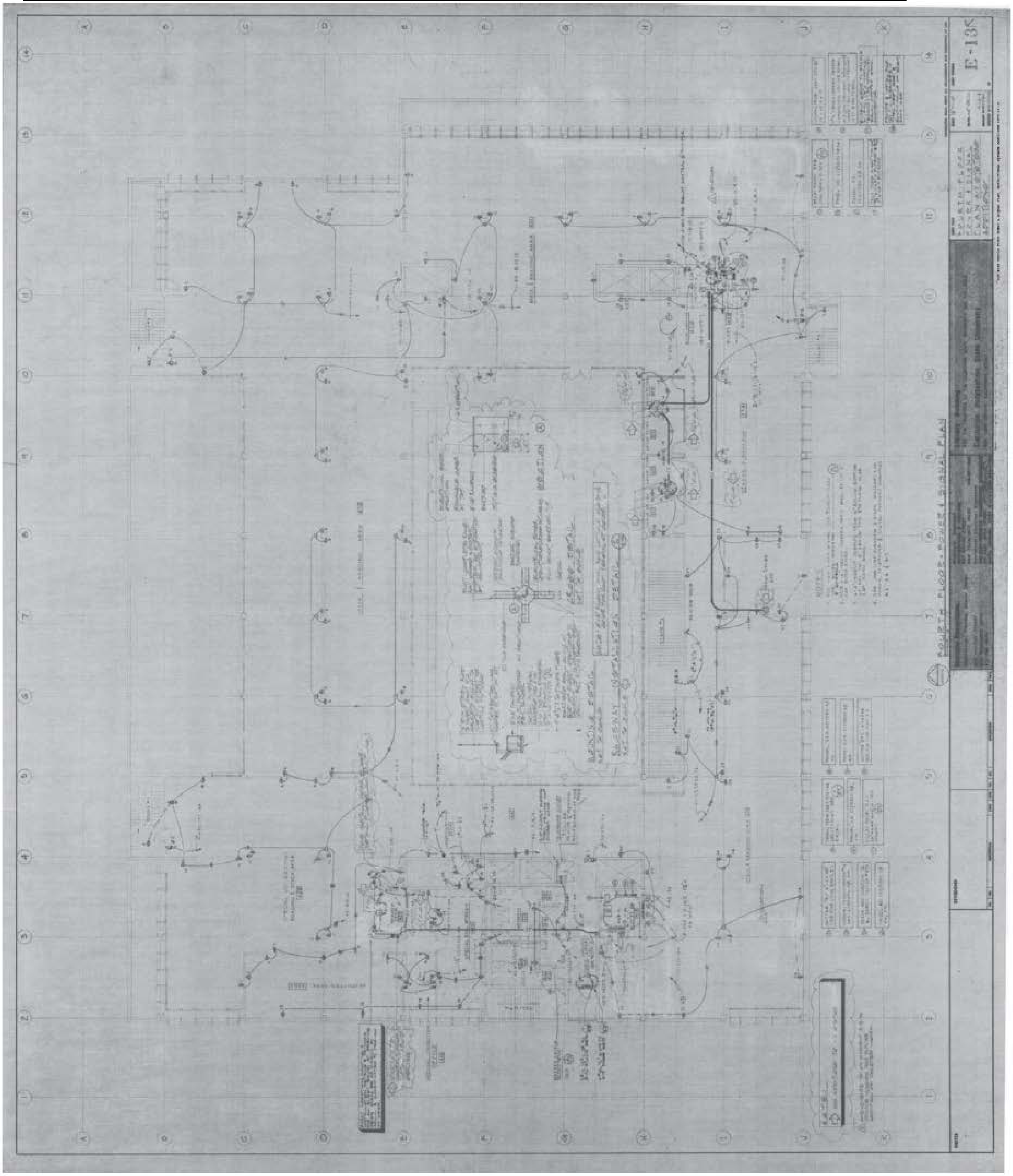


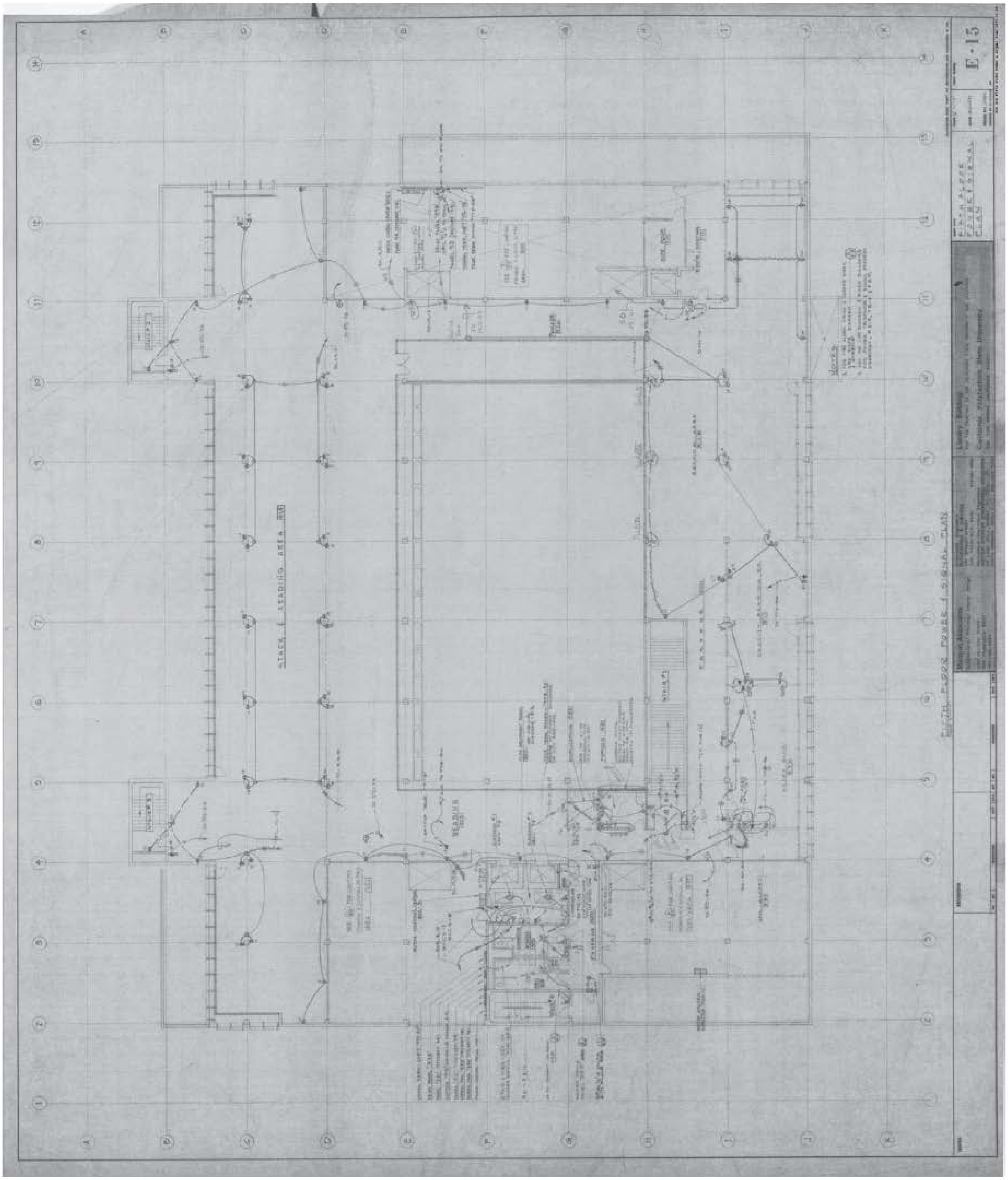


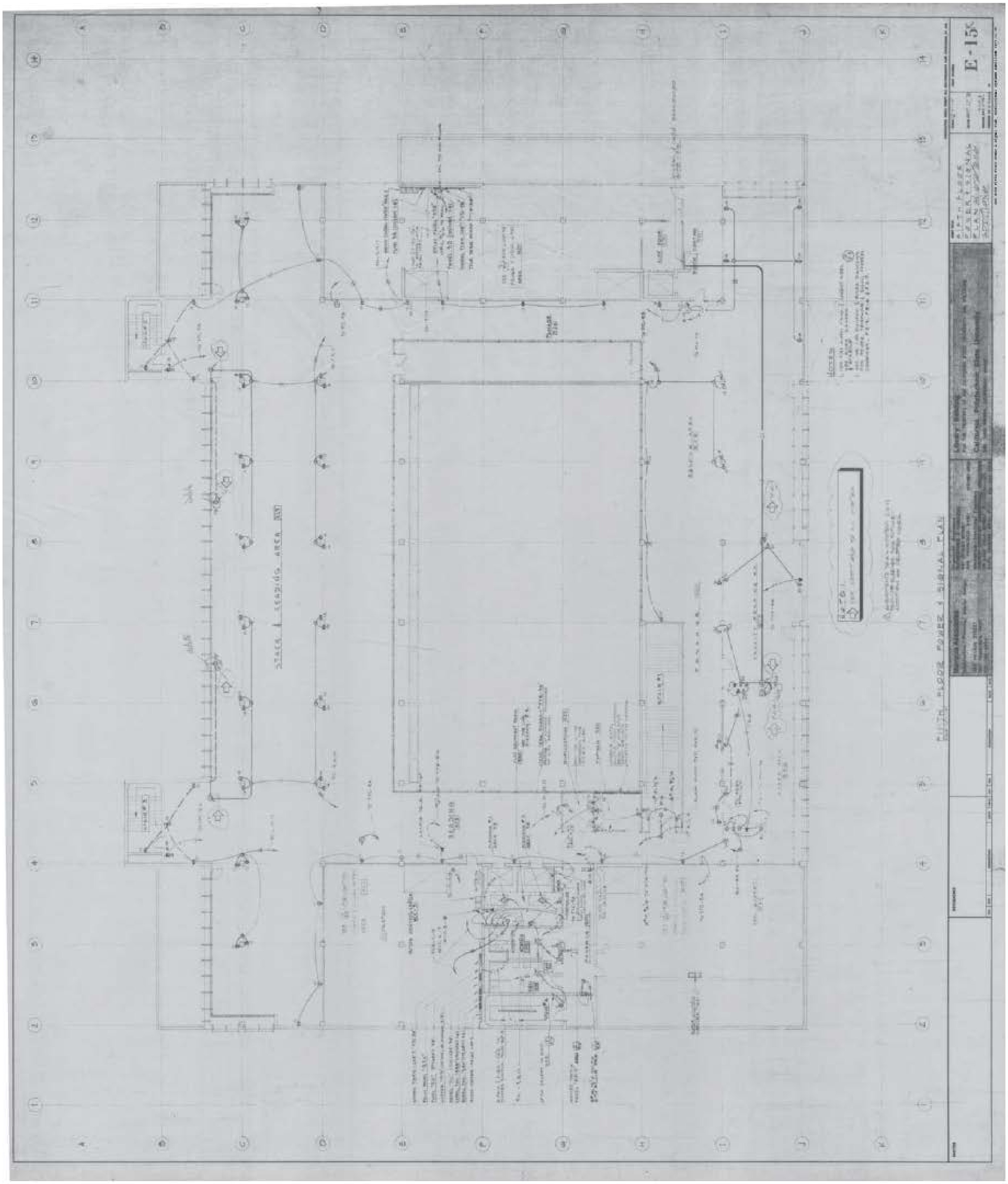



THIRD FLOOR - POWER & SIGNAL

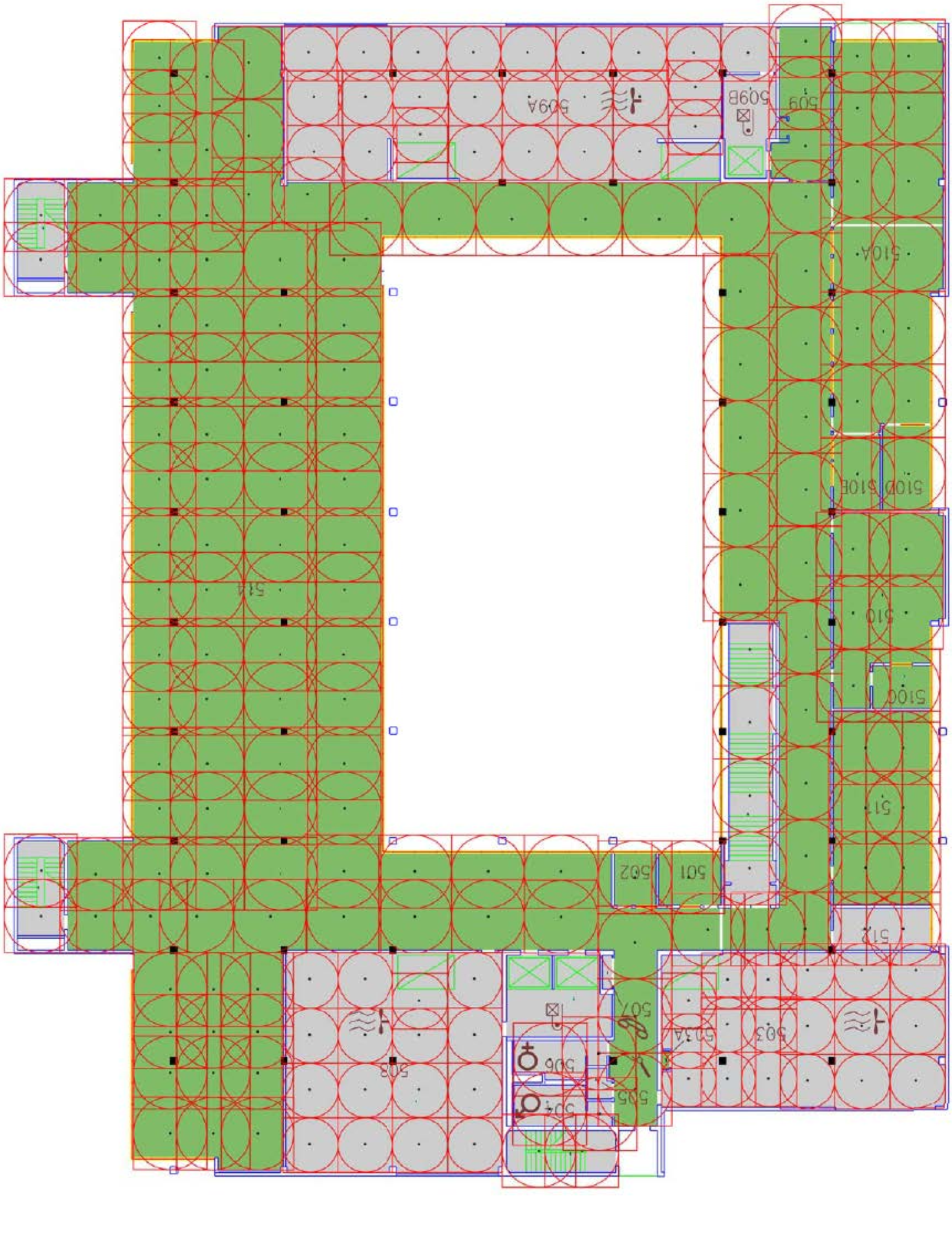


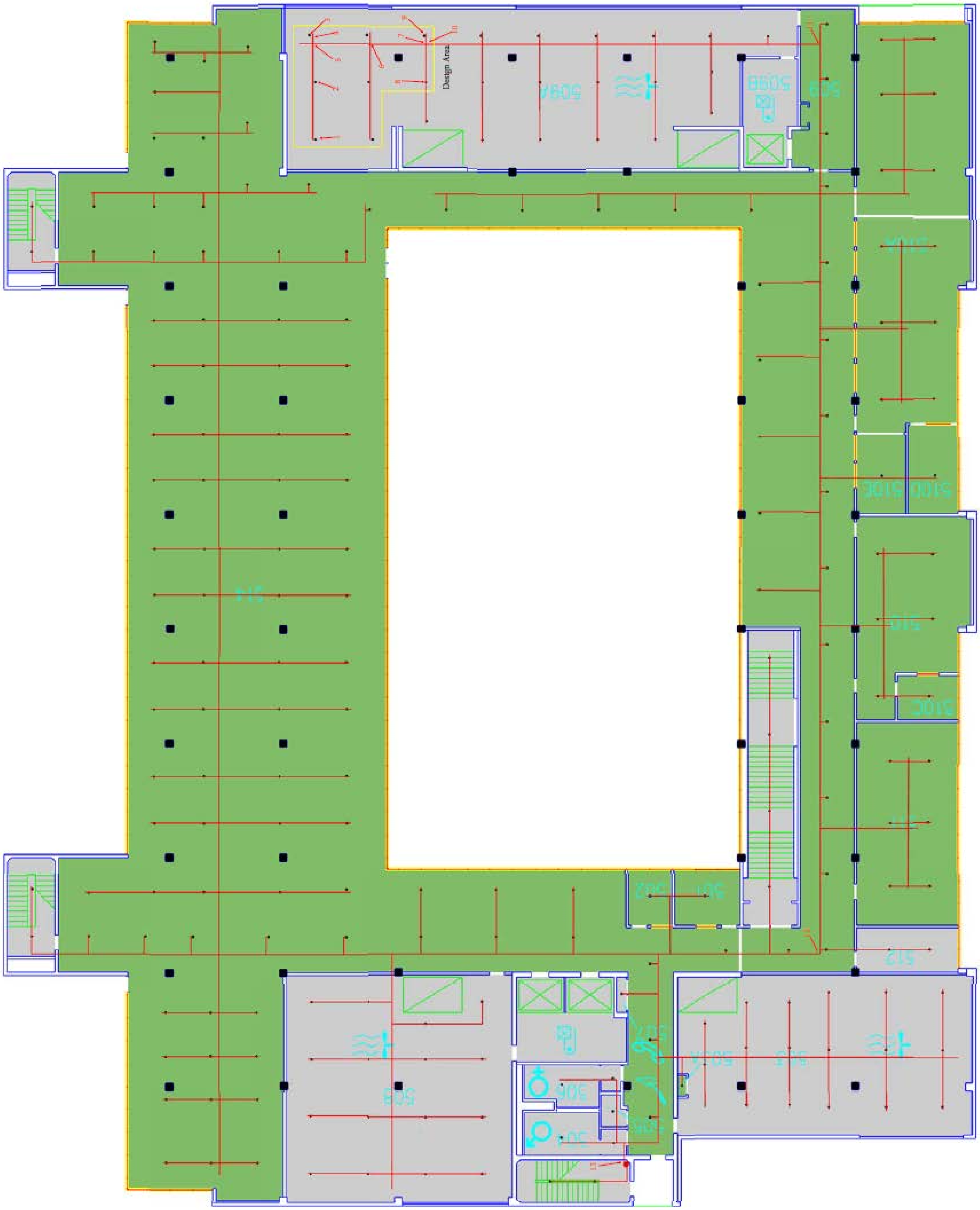



E-15



7.3. ATTACHMENT 3 – SPRINKLER LAYOUT AND NODE LOCATION DRAWINGS




Design Area