THE
ACME BUILDING
FIRE HAZARDS ANALYSIS

Review of the structural and life safety performance of the ACME Building in fire conditions

Russ Livesay, June 30, 2023, Rev 2

Statement of Disclaimer

KEYWORDS:

Performance-based Analysis, Prescriptive Analysis, Fire Dynamic Simulator (FDS), RSET-Required Safe Egress Time, ASET-Available Safe Egress Time

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EXECUTIVE SUMMARY

This Fire Hazards Analysis (FHA) was written using modern fire protection engineering principles to characterize the Applied Chemistry Management and Enrichment (ACME) Building at the Pacific Northwest National Research Area (PNNRA) using both a prescriptive-based and performance-based analysis to ensure the building and occupants can be safe in fire conditions. Recommendations are made as part of this analysis to improve the survivability of this structure if a fire were to occur.

This building was found to be compliant with the prescriptive code requirements from the 2018 International Building Code except for a few minor issues that are currently being repaired. The requirements from the international building code that were reviewed include but are not limited to the following:

1) Area and height specifications from Chapter five.
2) Fire rated construction from Chapter seven.
3) Interior finish requirements as found in Chapter eight.
4) Sprinkler and fire alarm stipulations as discussed in Chapter nine.
    a. Review from the 2019 NFPA 13 for sprinkler systems
    b. Review from the 2019 NFPA 72 for fire alarms
5) Means of egress designations as found in Chapter 10 that include but are not limited to:
    a. Travel distance limitations
    b. Exit placement
    c. Emergency signage and lighting
    d. Corridor, door, and stairway sizing
    e. Exit discharge
6) Retroactive applicability from Chapter eleven of the 2018 International Fire Code was also reviewed.

The performance analysis portion of this report involved several design basis fires. These involved gasoline and diesel pool fires, vehicle fires, and workstation fires used to estimate the time for sprinkler activation, determine the time requirements for safe egress, and the capability of the building contents to resist fire spread. The main finding was that the west high bay location used for loading shipping trailers has the potential for serious consequences for fire spread if a truck fire were to occur and combustible storage was not adequately controlled. The sixty foot high ceilings require a significant fire to trigger sprinklers and the suppression will likely not control fire growth. The results from the remainder of the design basis fires show acceptable performance for the structure and occupants in fire conditions.

The ACME Building is acceptable for continued operations. With minor exceptions, it meets current code requirements. Personnel can safely egress if a worst-case fire scenario occurs. Recommendations include changes in the storage configuration in certain areas, minimization of the use of wood pallets and caution regarding the use of trucks that are parked within the facility during offloading.

SCOPE

This document provides an engineered FHA for the ACME Building complex at PNNRA. This analysis evaluates the Life Safety Systems and the architectural design to determine if it meets acceptable safety requirements. It also identifies any outstanding deficiencies that represent a code non-conformance to the Alternate Code Of Record (ACOR).

The nature of the ACME Building's 1959 legacy construction resulted in a building that was not constructed to today's strict building codes. Modern building codes are designed primarily for occupant survivability with structural survivability as a secondary purpose. This analysis attempts to use both a prescriptive analysis with today's building codes and a performance-based analysis to determine two goals: 1) can personnel safely egress during a fire emergency, and 2) can the building structure survive a fire situation.

This analysis used several codes and standards to ensure compliance is met. Chapter 11 of the 2018 International Fire Code (IFC), Reference (a), specifies minimum retroactive requirements and was used as a baseline for determining if upgrades are necessary. The 2018 International Building Code (IBC), Reference (b), was used to determine deviations that should be noted that did not need to be updated based upon the requirements of Chapter 11 of Reference (a). The ACME building complex was determined to comply with the building requirements except for a few minor issues that shall be noted within this document. The codes identified in Table 1 are derived from the years of construction shown in Figure 1.

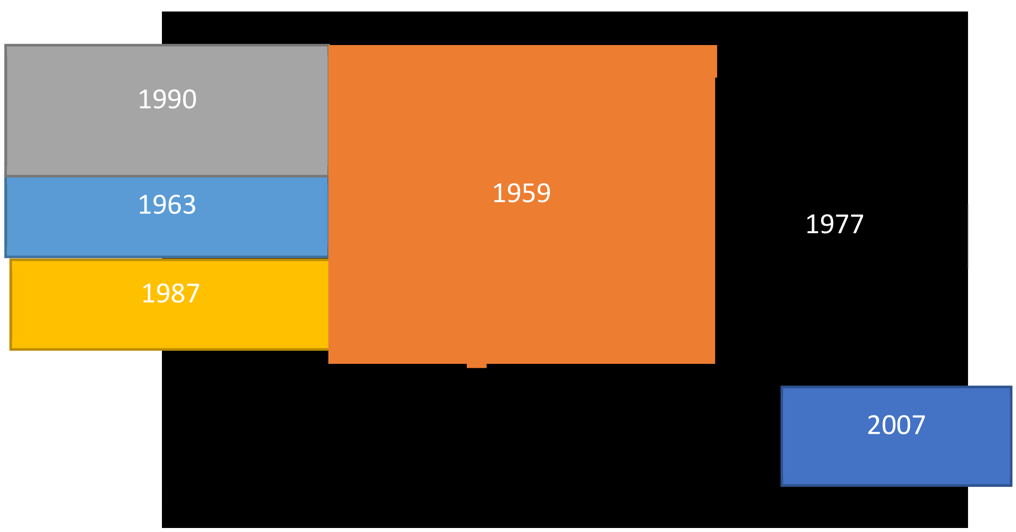


Figure 1: Approximate years of construction for additions to the ACME Building.

Table 1: Code of Record.

Application	ACOR	Applicable	Edition
Building	The following assignment for the Building Code is based upon the years of construction.	Applicable	
	1959 constructed main building areas:		1958 UBC
	1963 constructed west bay loading area:		1961 UBC
	1977 constructed east portion:		1973 UBC
	1987 constructed southwest addition:		1985 UBC
	1990 constructed northwest addition:		1988 UBC
	2007 constructed southeast extension:		2003 IBC
Electrical	NEC (National Fire Protection Association [NFPA] 70), National Electrical Code	Applicable	Based upon construction year as indicated for the Building Code.
Existing Building	State Adopted International Existing Building Code	Applicable	Current
Fire	State Adopted Fire Code	Applicable	Current
Fuel Gas	State Adopted Fuel Gas Code	Varies based upon date of construction	
Mechanical	State Adopted Mechanical Code	Varies based upon date of construction	
Plumbing	State Adopted International Plumbing Code	Varies based upon date of construction	
Fire Alarm and Signaling	NFPA 72, National Fire Alarm and Signaling Code	Applicable	2010
Portable Fire Extinguishers	NFPA 10, Standard for Portable Fire Extinguishers	Applicable	Current as referenced in the IFC
Sprinkler Systems	NFPA 13, Standard for the Installation of Sprinklers	Applicable	For compliance analysis, use the 1989 version for all the ACME Building except the southeast extension, which uses the 2002 version.
Inspection, Testing, and Maintenance of Water Based Fire Protection Systems	NFPA 25, Standard for the Inspection, Testing and Maintenance of Water Based Fire Protection Systems	Applicable	Current as referenced in the currently adopted IFC

FINDINGS AND OBSERVATIONS

This FHA has found the ACME building complex acceptable for operations with recommendations for improvement.

Combustible Storage:

Combustible construction in combination with the existing fuel loads within the business and storage occupancies of the building could result in fire spread in the absence of suppression and manual firefighting operations. A solution to minimize the potential for fire spread is to reduce combustible loading by using 6-sided metal cabinets such as file-cabinets to store combustibles such as books, paper, and other hand-packable items. This should be applied to both office and production areas as practicable. NFPA recognizes a 90% reduction in combustible loading by using fully enclosed metal cabinets to store combustibles. Overall, the combustible loading for this building is low in comparison with buildings used for similar activities.

Combustible Vehicles:

The potential for major fires involving tractor trailers is a key risk to the survivability of the ACME Building. Such vehicles are also a necessary part of the operations of this building. Both spill control pans beneath tractors while they are parked inside the ACME Building and staged wheeled CO_2 extinguishers with hose lines adjacent to such vehicles are required for all large trucks parked within the ACME Building. A minimum 10-feet offset is also required from such vehicles to combustibles, such as wood crates. Figure 109 shows a Heat Release Rate (HRR) profile for a typical truck fire, which shows a Peak HRR (PHRR) of 31 MW. A typical trashcan fire averages about 5 kW with a PHRR on the order of 30 kW. To put this into perspective, the truck fire represents about 1,000 trash cans burning simultaneously and should be managed with a high level of attention.

Combustible Construction:

New construction of buildings performing the kind of operations currently being undertaken within the ACME Building require non-combustible construction per mandatory requirements. Any new additions or modifications shall be constructed of non-combustible or limited combustible materials. Existing combustible construction within the ACME Building is acceptable because the industrial processes performed in the ACME Building are considered low-hazard work and are governed by policies and procedures that provide a high level of protection for occupants. Furthermore, operations are performed within the ACME Building by a highly trained workforce.

Compartmentation:

A defense in depth fire safety strategy requires multiple layers of protection within the design of a building. Compartmentation and fire rated construction is an important part of that strategy. There are inadequate fire barriers to support time to burnout within rooms at the ACME Building if the fire suppression system was disabled and manual firefighting operations were limited. If the fire suppression system becomes dysfunctional, it is possible that the fire could spread resulting in the potential for partial building collapse. Existing fire barriers are required to be maintained. Penetrations through non-combustible construction, whether the penetrations are through rated construction or not, are recommended to be sealed with fire rated materials. An example of fire rated construction is shown in Figure 7. This door is frequently propped open. This issue has been identified numerous times but is repeatedly found in this deficient condition. Personnel in this area have stated they prop the door open due to heating issues that make it too hot in this area. Action is necessary to resolve this situation so this fire rated barrier can be appropriately managed.

Means of Egress (MOE):

1. The wood risers on the stairway from the electricians' shop in the Handling Cask Orientation Gallery (HCOG) going up to the sign making mezzanine have riser and tread dimensions that violate allowable dimensions for existing construction. This area is currently barred from access.
2. The spiral stairway shown in Figure 14 goes from the Facility Manager's office into a small, caged area in the Fan Room. This is permissible as an equipment access stairway and is not considered impactful to the ability of personnel to safely egress.
3. The main door exiting from the first-floor operations area near the HCOG swings in the opposite direction of flow. The door is currently undergoing repair to resolve this non-compliance issue. This door is shown in Figure 10. This door serves a fire rated barrier and is propped open because of the egress flow issue. This violates the requirements for fire rated opening protectives.
4. The catwalk that goes west from the Door 52 waste processing area has areas with narrow widths that violate standard MOE paths; however, this area is more of an equipment access path so does not violate the intent of the code. This catwalk is shown in Figure 58. Typical MOE paths in non-public areas of the industrial portions of the ACME Building are permitted to be 28 inches in width per Section 1018.5 of Reference (a) when serving under 50 people. Section 1020.2 of Reference (a) allows for reductions down to 24" for equipment access, making obstructions in this location safe for the limited population it serves.
5. At Col 23 it is possible to egress from the south side of the water-pool processing area via the waste processing area. However, the exterior door is commonly obstructed by carts and containers.
6. Work areas in the Fan Room, which is shown in Figure 54 adjacent to the hot cell ventilation platform on the north side of the building, have a common path of travel that exceeds the 100' limit. This is not concerning due to the "equipment-access" nature of this location and the infrequency of personnel accessing this location.
7. The Equipment Pit under the water pool processing area has a single spiral staircase and exceeds the allowable common path of travel distance. This is an area that is blocked from access and is guarded during the occasional inspections when personnel enter, so it is not concerning. The cage restricting access to this area is shown in Figure 56.
8. There are access controlled locations that require turnstile access; however, these locations do have alarmed crash doors so do not create any impediments that would prevent the timely evacuation or prompt rescue of personnel in the ACME Building. An example is shown in Figure 9.
9. The Cratering Dry Proctoring (CDP) elevator pit only has one exit access associated with it. It has an excessive common path of travel in violation of Table 1006.2.1 of Reference (a). The stairway leading to this location is shown in Figure 60. The CDP high bay ceiling height provides significant volume to absorb smoke and allows for an increase to the egress time so personnel can safely exit this equipment pit even with this existing deficiency. This issue is not concerning and does

not deserve additional actions other than having personnel that work in this area briefed concerning this issue.

10. The elevator pit in PNNRA-438 has unique features that could result in slowed egress due to overall common path of travel lengths and equipment obstructions. PNNRA-438 has high ceilings and a large air volume that will significantly increase the available time to safely egress. Any MOE deficiencies in this area are not considered impactful to the safe egress of occupants.

Safety Significant Features

Table 3.3-T1 in PNNR S6698, "the ACME Building Servicing Manual," Reference (b.1), specifies the ACME Building support systems that include the following:

1. Primary and Backup Power
2. Cranes
3. Fire Protection
4. Fill, Drain, Cooling, Level Indicating, Nitrogen Purging, Hydrogen Monitoring, and Cold Weather Precautions

Section 1018.6.B of the PNNR S6678, Building Code Manual, Reference (ff), requires that the inadvertent operation or failure of fire suppression systems must not result in the loss of function of safety significant systems. There is no analysis that provides a fire survivability analysis of these safety significant systems if suppression is not functioning.

Sprinkler Fire Department Connections (FDC):

There is adequate signage and system information for the FDCs on the exterior of the building except for the FDC shown in Figure 130. A sign should be mounted to show what suppression system this FDC serves to avoid confusion. There needs to be adequate verification to ensure the Fire Alarm System (FAS) is appropriately addressing which suppression riser flow switch is activated so fire department personnel can easily identify the correct FDC for hookup based upon the FDC signage.

Sprinkler Nameplates:

the ACME Building has nine separate suppression zones. Riser tags or nameplates are lacking key information on many risers. This is non-compliant with installation standards at the time of construction as well as current code standards and should be fixed.

Sprinkler Seismic Restraints:

Many of the ACME Building sprinkler water delivery pipes lack seismic restraint protection. It is recommended that risers and bulk mains are inspected and brought up to the current code regarding seismic restraints where practicable. The results from seismic damage to the large water delivery lines such as the risers and bulk mains will result in a rapid flooding event within the building complex and will reduce or eliminate the ability of other sprinkler systems on site from properly functioning.

Suppression Obstructions (non-violation):

There are some minor architectural blockages for the pre-1990 sprinkler installations that would violate the current version of NFPA 13. These do not violate the code at the time of installation. This non-conformance does not violate the principle behind suppression as supported by the modern NFPA 13 handbook commentary which states that when "architectural features interfere with the sprinkler's spray pattern . . . these shadowed areas are purely on paper and do not take into account the dynamic variables of sprinkler discharge." It is recommended to eliminate such blockages only if the sprinkler system is upgraded or repaired in the vicinity of such minor blockages.

Suppression Obstructions (violation):
There is a large door at the ceiling of the high bay that blocks sprinkler heads and is inadequately tested. This door was installed to close an opening in the wall where the original building ended its west side at this location (column line 3), but crane rails extended to the west exterior of the building. The 1963 construction resulted in the west expansion of the high bay. This door should be removed as it blocks sprinkler discharge and impacts the ability of the hot ceiling jet from a fire's smoke plume to access the heads and trigger them. Inspection, Testing and Maintenance (IT&M) could resolve this issue if the proper equipment is in place to cause the door to properly close and not block sprinkler heads. The easiest solution is to remove this door. The reason this door is not concerning from a principles basis is that the high bay at this location is approximately 60' high and the minimal combustibles stored under the heads would completely burn out prior to those sprinklers activating.

Suppression Weakness:
The Tool Room in PNNRA-117 does not have adequate sprinkler protection for the type of storage taking place. The current configuration does not meet today's NFPA 13 requirements for a storage occupancy. Recommendations for reconfiguring the storage rows are made in the conclusion of this report.

BUILDING DESCRIPTION

the ACME Building is broken into different areas as follows:

- PNNRA-517 – This is the main building that includes the 1,000-feet long east-west high bay area and adjacent office and processing areas.
- PNNRA-117 – This is the Tool Room warehouse on the southwest side of the building that was constructed in 1987.
- PNNRA-878 – This is a training facility and machine shop attached to the northwest side of the building in 1990.
- PNNRA-438 – This process area was added to the building in 2007 on the southeast side.

The initial construction of PNNRA-517 (between Columns 3 and 20) was completed in 1959. Significant additions and alterations were constructed in 1963, 1977, and 1989-1990. Several interior modifications have been made including modifications to process pools as part of the various building additions. A processing upgrade project was also completed in the late 1990’s that incorporated new ventilation equipment.

Initially, rail cars entered the facility through the west wall at the column originally marked as #3 within the building. The 1963 expansion shown in Figure 1 extended the ACME Building from column #3 to the present Column Line of 12A.

The PNNRA-517 High Bay is separated from the south portions of the building by metal paneling, masonry and transite panels. The separation assembly is porous and allows air transfer from one area to the other.

The main portion (PNNRA-517) of the ACME Building is a steel frame structure with steel truss roof supports. High Bay roof support columns are spaced approximately 20-feet on center. A series of crane columns run along the 1,000-feet length of the high bay. The crane columns are not independent of the building columns. None of the structural steel or roof truss members has an applied fireproofing material.

Roofs are metal deck with approximately four inches of insulation, built-up roofing, and aluminized coating. Exterior walls are generally masonry up to 10-feet, with insulated metal panel finish for the full height.

Interior partitions separating the high bay from the office areas are masonry and extend the full height of the two-story office portion. Partitions separating the High Bay from Buildings PNNRA-117 and PNNRA-878 are full height masonry partitions. Other major partitions are partial height masonry walls with transite panels extending to the ceiling.

the ACME Building has several mezzanines, equipment platforms and equipment pits. A few of these include the electrical equipment mezzanine on the northeast portion of the high bay, along with a Heating, Ventilation and Air Conditioning (HVAC) mezzanine just south of it. A process mezzanine is located at the east end of the high bay and is a freestanding structure. Process related equipment pits are in the narrow high bay just south of the main high bay and are also within PNNRA-438. Another pit runs under the water pools and is accessible via a spiral staircase on the west side of water pool 1 and through a hatch in the observation deck under the north walkway adjacent to the center water pools in PNNRA-517.

Most construction materials and interior finish is of limited combustible material; however, combustible construction does exist primarily within the office areas of PNNRA-517. Some examples of combustible construction include:

- The walls of some of the PNNRA-517 high bay offices, include the Waste Office, Lifting and Handling Operations Office, and the Lifting and Handling Engineering Office, located near columns 3-D to 5-D have combustible construction. They are constructed of corrugated paper cores sandwiched between two layers of ½" gypsum board. These panels are supported in an aluminum frame. Although the aluminum frame protects most of the edges of the panels, the paper core was visible at gaps in the panels and at damaged areas.
- A wooden parapet wall is located on the roof of the shops between column lines E-11 to E-14 on the south side of column line E.
- The rooms above the shops between columns E-3, E1-3, E-8, and E1-8 are constructed of gypsum board on wooden studs. The ceiling structure is made of wood joists.
- The electricians' room at the west end of the operating gallery near column 6-C contains a mezzanine and stairs of wooden construction. The mezzanine is constructed of dimensional lumber joists with a plywood walking surface.
- An office located at Column 35-B2 is constructed of wall panels with a polystyrene core sandwiched between two layers of gypsum board. The panels are supported in an aluminum frame.
- PNNRA-878 has a modular office located at Column B-2 on the north wall of the building. It is constructed of panels of fiberboard wall surfaces mounted to a polystyrene core, supported in an aluminum frame. This office is shown in Figure 48.

Based upon existing AutoCAD drawings, the ACME Building has a gross area of approximately 250,000 ft^2 (including mezzanines and platforms but excluding equipment pits). This building is a mixed Group-B, Group S-1, and Group F-1 occupancy with accessory Group U, A-2, and A-3 areas meeting the requirements of Section 508.2 of Reference (b).

Protection Category

PNNRA has assigned categories to its buildings in accordance with standards set by the State Energy Commission (SEC) based upon their mission need and potential impact in the event of collapse. This Performance Category (PC) scale goes from PC-0 through PC-4, with 4 having the greatest potential impact. The ACME Building has been assigned a Natural Phenomenon Hazard PC of PC-3. This is discussed in PNNRA-PPP-1017, Reference (d) and is assigned this level due to the mission dependency and hazard nature that the ACME Building protects.

Natural Hazards

PNNRA-PPP-00018, Reference (e), specifies historical natural phenomena hazards, and identifies design criteria for natural events. This information includes seismic, wind, and flood events that could impact PNNRA.

SEISMIC

The largest recorded earthquakes in the vicinity of the PNNRA are the 1969 Morrow Lake earthquake near Yosemite with a Moment Magnitude (MM) of 7.3 and the 1979 Butte Peak earthquake 46 miles northwest of PNNRA with an MM of 6.9. Another earthquake with an MM of 6.5 occurred on March 31st, 2010, about 19 miles northwest of Stanley, Nevada, and was felt at PNNRA. The PNNRA Construction Engineering organization has confirmed that seismic analyses of the ACME Building have shown that its structure was designed with sufficient capacity to survive anticipated seismic events. Notwithstanding this conclusion, conservatism should be taken in the overall fire protection strategy to minimize the potential for fire related damage that could result from a severe seismic event given the history of seismic activity in the region.

WIND

Severe weather events that can affect PNNRA include thunderstorms, strong winds, hail, tornadoes, snowstorms, and dust devils. There were no tornadoes (vortex reaches the ground) reported within the PNNRA boundaries since 1950. However, in all southeast Nevada between 2000 and 2010, there were approximately five short-lived, small tornados reported. Average annual wind speeds at the PNNRA Central Facilities Area (CFA) 20-foot tower are about 7.5 miles per hour. The highest hourly average near ground wind speed measured for CFA was 51 miles per hour from west-southwest, with a maximum instantaneous gust of 78 miles per hour. The United States is divided into three regions based on the wind speed and probability of tornados and hurricanes with Region 1 as the most active. Region III is not designed for hurricanes and has very rare, relatively small tornados. PNNRA is in Region III. A tornado could cause an electrical fire within or adjacent to the ACME Building, but due to the non-combustible type of construction and very limited combustible loading, a significant fire event is not expected from wind within the ACME Building.

FLOODING

River flooding can be caused by precipitation anywhere in a river's watershed. PNNRA does not reside in the 100-year or 500-year floodplains of the Big Lost River. The bounding Probable Maximum Flood (PMF) with the failure of the Jones Dam for PNNRA is at a water level of 4851.9-feet above sea level. The PMF results in a couple feet of water above the finished first floor of the ACME Building. The time between the initiation of a PMF and the arrival of flood waters at PNNRA is sufficient (greater than 16 hours) to suspend normal operations and place the facility in a secured position.

WILDLAND FIRE

Wildland fire is a severe threat to PNNRA. The open wildland provides substantial combustible loading, consistently high winds, and hot and dry conditions in the summer months. These conditions are mitigated by a 50-foot swath of mowed wildland vegetation around the fence line. Additionally, at least 20-feet of vegetation is cut on either side of roads. Special actions are taken during wildland fire season that prohibits most combustibles from being stored within 10-feet of any buildings. Vegetation accumulations are also removed from around buildings. The ACME Building has an open area around it that is kept free of most dry vegetation and is better protected from wildland fire threats than many of the other buildings at PNNRA. Unscreened windows and doors are kept closed if wildland fire is approaching PNNRA. This will keep blowing embers from entering the ACME Building and creating a fire hazard.

Photographs of the facility

The subsequent Figures 2 through 64 are included in this document to help the reader understand the nature of the combustible controls, storage of hazardous materials and the general conditions of the facility. These images are representative and not actual photographs due to the owner's need-to-know related concerns that prevent actual images from being included in this report.

Figure 2: A section of a Trade Storage Area (TSA) on the southeast side of the ACME Building.

Figure 3: A portion of a TSA location at the southeast side of the ACME Building.

Figure 4: TSA on the north side of the ACME Building that stores compressed nitrogen gas.

Figure 5: Exterior exit example. This is shown as Balloon 57 in Figure 71.

Figure 6: Entry from the east side of the ACME Building near the operations' breakroom.

Figure 7: The fire door next to breakroom (Balloon 78 in Figure 72).

Figure 8: Sewing Fragments Processing Facility (SFPF) personnel breakroom.

Figure 9: Near the SFPF breakroom. Notice that adjacent Door provides egress.

Figure 10: Door #112. This door opens against the flow of egress.

Figure 11: Room behind the door labeled as #132 near the HCOG.

Figure 12: HCOG shown as Balloon 24 in Figure 69.

Figure 13: Room behind the door labeled as #136 in the HCOG.

Figure 14: Spiral staircase from the Facility Manager's office, which leads to the Fan Room.

Figure 15: Sailmaker's shop on the northeast side of the ACME Building.

Figure 16: Corridor inside of Door N-26U on the north side of the ACME Building.

Figure 17: Bathroom on the north side of the ACME Building behind the door marked as 113.

Figure 18: Office area on the north side behind door 117.

Figure 19: Office behind door #116 on the north side of the ACME Building.

Figure 20: Office behind door #118 on the north side of the ACME Building.

Figure 21: Office behind door #119 on the north side of the ACME Building.

Figure 22: Area next to the Plan of the Day room on the north side of the ACME Building.

Figure 23: Plan of the Day room behind door number 124 on north side.

Figure 24: Office behind door numbered 125 on the north side of the ACME Building.

Figure 25: Office behind door 121 on north side of the ACME Building.

Figure 26: Planning and Production manager's office on north side.

Figure 27: North-south main 1^{st} floor corridor.

Figure 28: Operation manager's secretary's office behind door 102.

Figure 29: Operation manager's office on north side of the ACME Building.

Figure 30: the ACME Building lunchroom on the north side of the building.

Figure 31: Office area accessed from the ACME Building lunchroom.

Figure 32: Work crew briefing room behind door 107.

Figure 33: Janitors' closet behind door 107.

Figure 34: North-south first-floor corridor facing to the north.

Figure 35: First-floor bathroom behind door 110.

Figure 36: Fire alarm signaling panels near door 112A.

Figure 37: Mens' locker room near door 112A.

Figure 38: Document Control room.

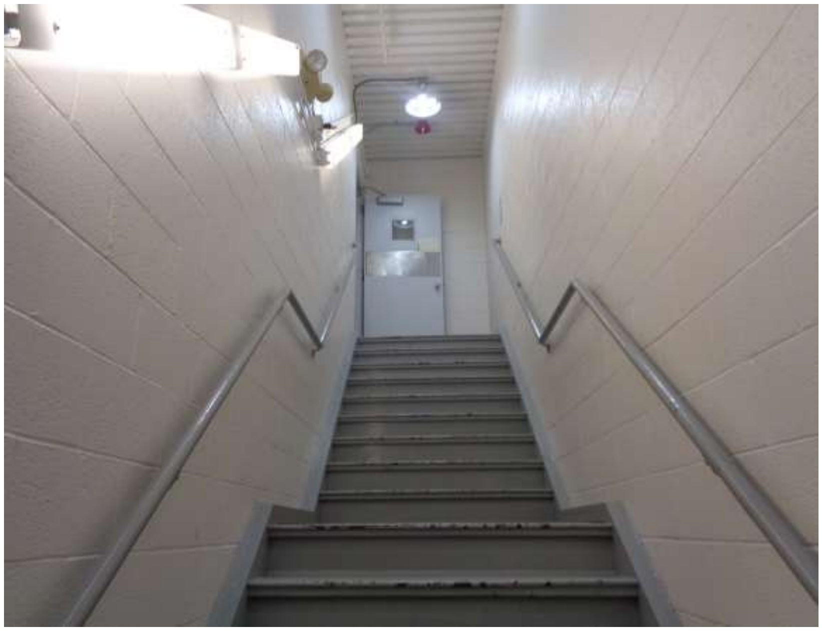


Figure 39: Interior exit access stairway from the lunchroom.

Figure 40: North-south corridor facing to the north on the 2nd floor.

Figure 41: Office area behind door 211.

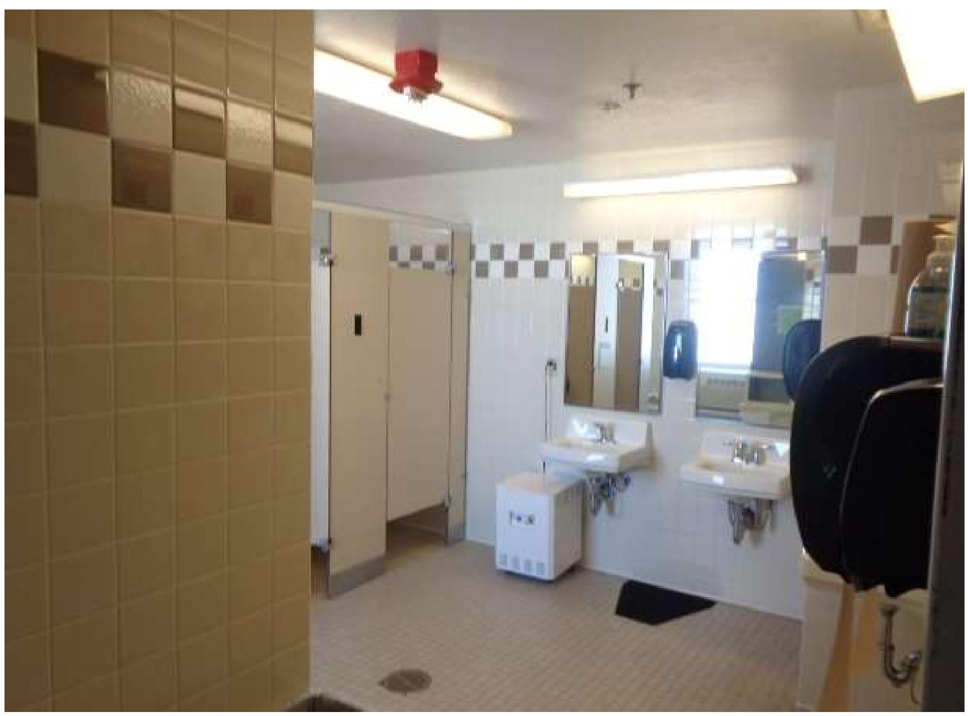


Figure 42: 2nd floor central men's room on the north side of the ACME Building.

Figure 43: 2nd floor office area shown as Balloon 120 in Figure 77.

Figure 44: the ACME Building Classroom #220 behind door 226.

Figure 45: Office area shown near Balloon 127 in Figure 77.

Figure 46: East hallway (205) on 2nd floor that leads to the exterior exit stairway.

Figure 47: Inside the PNNRA-118 machine shop.

Figure 48: Office in PNNRA-118.

Figure 49: Compressor room on the south side of the ACME Building behind Door S-61U.

Figure 50: Shipping area for waste from the Door on the south side of the ACME Building.

Figure 51: Location for the 45-foot separation distance between PNNRA-438 and PNNRA-695.

Figure 52: Location for the 41-foot separation distance between PNNRA-643 and PNNRA-636.

Figure 53: Main high bay in PNNRA-517.

Figure 54: 2nd floor fan room above the HCOG.

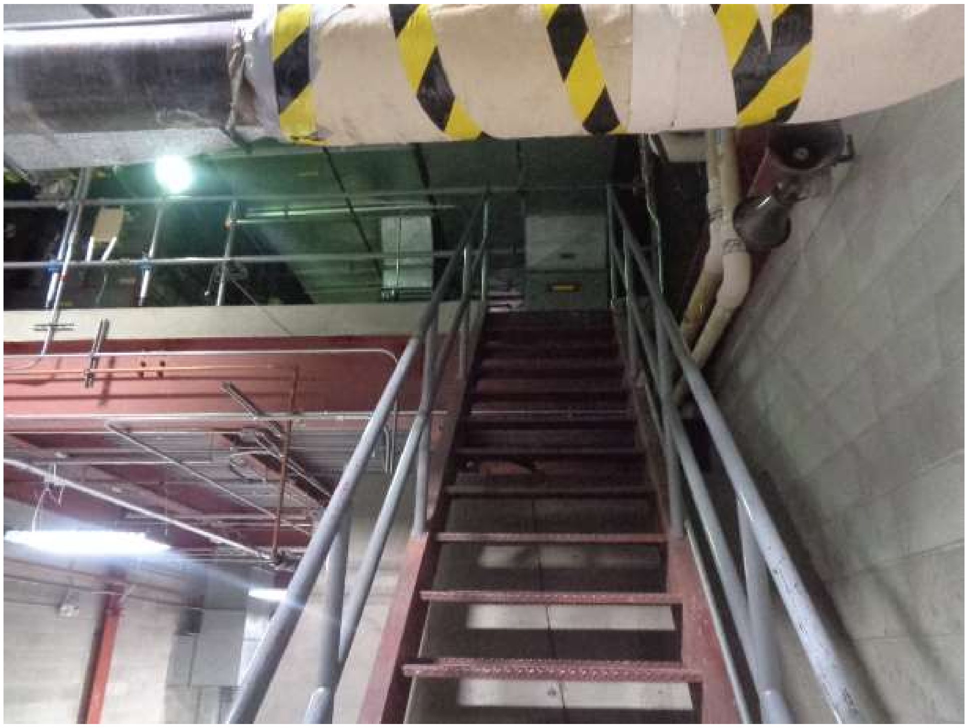


Figure 55: Mezzanine above the fan room.

Figure 56: Electrical gear at the west end of the water pool area.

Figure 57: Door 52 waste processing area just to the south of the main PNNRA-517 high bay.

Figure 58: Equipment access catwalk near the door 52 waste processing area.

Figure 59: The CDP area between PNNRA-438 and the PNNRA-517 high bay.

Figure 60: This is the stairway that leads to the CDP elevator equipment pit.

Figure 61: PNNRA-438.

Figure 62: Aisle within the elevator equipment access pit in PNNRA-438.

Figure 63: TSA behind door labeled as #144 within the PNNRA-517 high bay.

Figure 64: Observation deck under the PNNRA-517 high bay north beach.

IDENTIFICATION OF BUILDING USES

Application of building codes require a facility to be categorized as a particular occupancy or group of occupancies. This analysis breaks up areas both in terms of building code defined group-uses and actual uses to allow the assessment of each area based on the inherent hazard rather than a particular building code category.

The ACME Building is divided into several uses including office spaces, industrial areas, utility areas, storage spaces, conference rooms, break rooms, bathrooms, lockers, showers, and unoccupied areas. The unoccupied areas are prohibited for use due to legacy environmental concerns or egress concerns due to the age of the original construction. Those areas are either locked from access or administratively prohibited from use. No storage occurs in these areas. The industrial areas have sections that rely on remote access for operations, where personnel cannot access the space due to challenges, such as water-pools used for processing. These areas are assigned no occupant load.

Figure 65 shows an overall layout of the ACME Building for both the 1st and 2nd floors. This is broken out into zoomed-in images of Figure 65 shown in Figure 66 through Figure 81. The balloon numbers in the Figures correspond to the respective areas, occupancy use, and occupancy loads used in subsequent tables such Table 7. These figures are blacked out due to confidentiality concerns.

Figure 65: Overall view of the ACME Building with the respective occupancy uses.

[redacted]

Figure 66: Legend for the ACME Building Occupancy Use Drawings.

Figure 67: Area 1 of the ACME Building.

Figure 68: Area 2 of the ACME Building.

Figure 69: Area 3 of the ACME Building.

Figure 70: Area 4 of the ACME Building.

Figure 71: Area 5 of the ACME Building.

Figure 72: Area 6 of the ACME Building.

Figure 73: Area 7 of the ACME Building.

Figure 74: Area 8 of the ACME Building.

[redacted]

Figure 75: Area 9 of the ACME Building (2nd floor).

Figure 76: Area 10 of the ACME Building (2nd Floor).

[redacted]

Figure 77: Area 11 of the ACME Building (2nd Floor).

Figure 78: Area 12 of the ACME Building (2nd Floor).

Figure 79: Area 13 of the ACME Building (2nd Floor).

Figure 80: Area 14 of the ACME Building (2nd Floor).

Figure 81: Area 15 of the ACME Building (2nd Floor).

Asbestos

the ACME Building was used for asbestos work and has the potential for contamination spread. Most of the facility is clearly demarcated as an Asbestos Controls Area (ACA). Asbestos Material Storage Areas are found throughout the ACA. The Asbestos Controls required for Modification (ACM) areas outside of the ACAs are shown in the following two figures. Special precautions associated with release of material and any construction related tasks in these areas need to be taken and Asbestos Controls Engineering approval is required for any construction tasks in these areas.

[redacted]

Figure 82: ACM locations on the first floor of the ACME Building.

[redacted]

Figure 83: ACM locations on the second floor of the ACME Building.

Asbestos Hazard Categories for SEC buildings range from 1 to 3, with 1 being the most severe. The ACME Building is designated as an Asbestos Hazard Category of 2 per KEY-CES-00475, Reference (f). PDQ-78110-12-088, Reference (g), specifies that this designation is because of the quantity of asbestos material associated with spent lagging and destructive examinations.

STRUCTURAL CODE COMPLIANCE

Required Fire Rating

Throughout this analysis, current building and fire codes are used to ensure conservatism is met in the review of the fire safety features of buildings. One significant challenge of applying the ACOR to this building is that different versions apply to different sections of the ACME Building depending on when the respective portions were constructed. The review process for code compliance within this analysis is greatly simplified by using one code or standard during this process. Reference (b) shall be used for this evaluation.

Section 1020 of Reference (b) does not require fire rated construction for coridors within a sprinklered building. Both the interior and exterior stairways serving the second floor of the building do not have any fire rated protection and are open. An example of such a stairway is shown in Figure 39. They are viewed as exit access stairways not exit enclosures and the overall exit access travel path is applied from the most remote locations to the Level of Exit Discharge at the exterior of the building for any distance calculations. Section 1019.3.1 of Reference (b) does not require exit access stairways to be within a fire rated shaft if only serving exit access between two floors as is the case with all the exit access stairways that serve the second floors of the ACME Building. Additionally, the walls for the horizontal exits are required to be two-hour rated and will be discussed later.

Area Constraints

This building uses Type VB construction, meaning that combustible construction is used and no fire rating is applied to structural members. Most of this building is composed of concrete and steel; however, as discussed above, portions of this building do have combustible construction. Sections of this building rely on wood studded walls separating office space and one set of wood stairway stringers. The combustible construction is not separated by fire rated construction so this building must be considered a Type VB structure. Per Table 506.2 of Reference (b), the allowable area factor (A_t) is limited to 34,000 ft^2, which is the area based upon the most limiting occupancy type in this mixed occupancy building (Group F-1). This area limitation is modified because the ACME Building is adjacent to a public way for its entire perimeter and is sprinklered. The allowable area for a single story building based upon this area increase is:

A_a (allowable area) = $[A_t + (NS \times I_f)]$ *Reference (b) Section 506.2.1 Equation 5-1 (2018 506.2.4 Eq. 5-3)*

$A_t = 34{,}000\ ft^2$

NS (non-sprinklered area per Table 506.2 (2018)) = 8,500 ft^2

I_f (area factor increase) = $[F/P] - .25]W/30$ *Reference (b) Section 506.3.3 Equation 5-5*

F (frontage) = P(perimeter)

W = 30 *Reference (b) Section 506.3.2*

$I_f = 0.75$

$A_a = [34{,}000\ ft^2 + (8{,}500\ ft^2 \times 0.75)]$;

$A_a = 40{,}375\ ft^2$ *Area for a single story building*

As the ACME Building is a two story building, that maximum area value of 40,375 ft^2 is modified to a smaller area based upon the Sprinklered Multiple story (SM) row for multiple stories in Table 506.2. The values for area as based upon occupancy is show below in Table 2, which clearly indicates the ACME Building is larger than what is permissible by code for non-special use buildings.

Table 2: Allowable area calculations.

Area Allowances by Occupancy Classification for a Two-Story Sprinklered Structure Surrounded by ≥30’ Public Way				
Occupancy Classification	1st Floor Area	2nd Floor Area	Allowable Sprinklered (SM)	Allowable per Floor Area (A_a) for 2-story building [Reference (b) Eq. 5-3]
Group F-1	200,000	20,500	25,500	[25,500 ft^2 + (8,500 ft^2 X 0.75)] =**31,375 ft^2**
Group B	19,500	16,000	27,000	[27,000 ft^2 + (9,000 ft^2 X 0.75)] =**33,750 ft^2**
Group S-1	16,000	N/A	27,000	[27,000 ft^2 + (9,000 ft^2 X 0.75)] =**33,750 ft^2**

Per Sections 505.2 and 505.3 of Reference (b) the areas of mezzanines and equipment platforms shall not contribute to the building area of a structure. Even with these areas removed, the applicable floor area still exceeds what is permissible in non-special use buildings.

Although the above calculations show that the size of the ACME Building is significantly too large for typical buildings, Section 507.5 of Reference (b) specifies buildings can be of unlimited size if it is both sprinklered and if it is surrounded by a public way that is at least 60’ in width.

Although the ACME Building is sprinklered, it does not meet this 60’ offset. The following list of deviations exist where buildings are within 60-feet. These offset distances also represent the fire related exposures to and from adjacent buildings within 60-feet of the structure:

- The distance between PNNRA-117 and the adjacent staging warehouse (PNNRA-636) is 41’.
- The distance between PNNRA-517 and the Celite Tank House to its south (PNNRA-642) is 27’.
- The distance between PNNRA-438 and an empty former water tank (PNNRA-707) is 40’.
- The distance between PNNRA-438 and the well shed (PNNRA-611) is 24’
- The distance between PNNRA-517 and the 250 ft^2 janitors shed on the north side is 25’.
- The distance between PNNRA-878 and the guard shack is 23’.
- The distance between PNNRA-438 and the Fire Water Upgrade tank (PNNRA-695) is 45’.

Although the above area calculations were performed and building offset distances were measured, they do not apply in this case because the ACME Building is a specialized industrial building. The purpose for the above calculations was to demonstrate just how unusually large the ACME Building is, which emphasizes the need for maintaining existing fire rated barriers. Section 503.1.1 of Reference (b) does allow special industrial occupancies to have unlimited area and height due to required processes such as crane operations and activies as found in the ACME Building. Although this allowance exists, any proposed changes to fire rated construction within the ACME Building and the construction of any proposed buildings within 60’ of the ACME Building should be managed conservatively to mainintain as many fire barriers as possible due to the challenges of being larger than the current code allows for non-special use buildings.

Height

PNNRA-438 was constructed in 2007 and is separated from PNNRA-517 by an 8" concrete block wall. The personnel doors in this wall are listed for 90-minutes and have self-closers. There is a roll-up steel door located between columns G23 and G24 that is not a listed fire door which results in this wall not constituting a fire-rated separation. This 2007 addition would meet the requirements of a Type IIB structure if appropriately separated by three-hour construction per Table 707.3.10 as is required in mixed F-1 and B occupancies. PNNRA-438 is considered a Type VB building due to the absence of the required rated separation between the newer construction and the original building.

The height limitation for the design occupancy classifications of Group B, Group F-1, and Group S-1 is 60-feet for Type VB sprinklered construction. The ACME Building exceeds that height limitation with PNNRA-438 being approximately 100' high. The ACME Building is considered a special use occupancy so is permitted to be higher as specified in Section 503.1.1 of Reference (b).

Height and Area Summary

In the case of both area and height, this building would be considered non-compliant for typical uses. This building is a special industrial occupancy, and its size is necessary to support special industrial processes including crane-ways and special equipment. Section 503.1.1 of Reference (b) specifically exempts these types of buildings from needing to meet the building height and area limitations as specified in Sections 504 and 506 of Reference (b). This exemption justifies the existing height and area conditions of this building making it code compliant.

Interior Finish Requirements

Table 803.13 of Reference (b) specifies acceptable interior finish criteria for new construction (Table 3 below). This table specifies that Class C interior finish is acceptable for all portions of this building. The interior finish of this building does not exceed the Class C rating, so is acceptable. The Group A occupancies are accessory to the overall occupancies of the building, so do not invoke the Class B interior finish requirements for any exit access stairways or corridors.

Table 3: Table 803.13 from Reference (b) showing interior finish requirements.

TABLE 803.13
INTERIOR WALL AND CEILING FINISH REQUIREMENTS BY OCCUPANCY[k]

GROUP	SPRINKLERED[l]			NONSPRINKLERED		
	Interior exit stairways and ramps and exit passageways[a, b]	Corridors and enclosure for exit access stairways and ramps	Rooms and enclosed spaces[c]	Interior exit stairways and ramps and exit passageways[a, b]	Corridors and enclosure for exit access stairways and ramps	Rooms and enclosed spaces[c]
A-1 & A-2	B	B	C	A	A[d]	B[e]
A-3[f], A-4, A-5	B	B	C	A	A[d]	C
B, E, M, R-1	B	C[m]	C	A	B	C
R-4	B	C	C	A	B	B
F	C	C	C	B	C	C
H	B	B	C[g]	A	A	B
I-1	B	C	C	A	B	B
I-2	B	B	B[h, i]	A	A	B
I-3	A	A[j]	C	A	A	B
I-4	B	B	B[h, i]	A	A	B
R-2	C	C	C	B	B	C
R-3	C	C	C	C	C	C
S	C	C	C	B	B	C
U	No restrictions			No restrictions		

Load Bearing Walls and Fire Barrier Maps

Figure 84 and Figure 85 identify the main Reference (b) defined occupancy classifications and identify the existing fire rated construction and where the load bearing walls are located. These images also show the overall principal occupancy type as used in performing the area analysis as shown in Table 2.

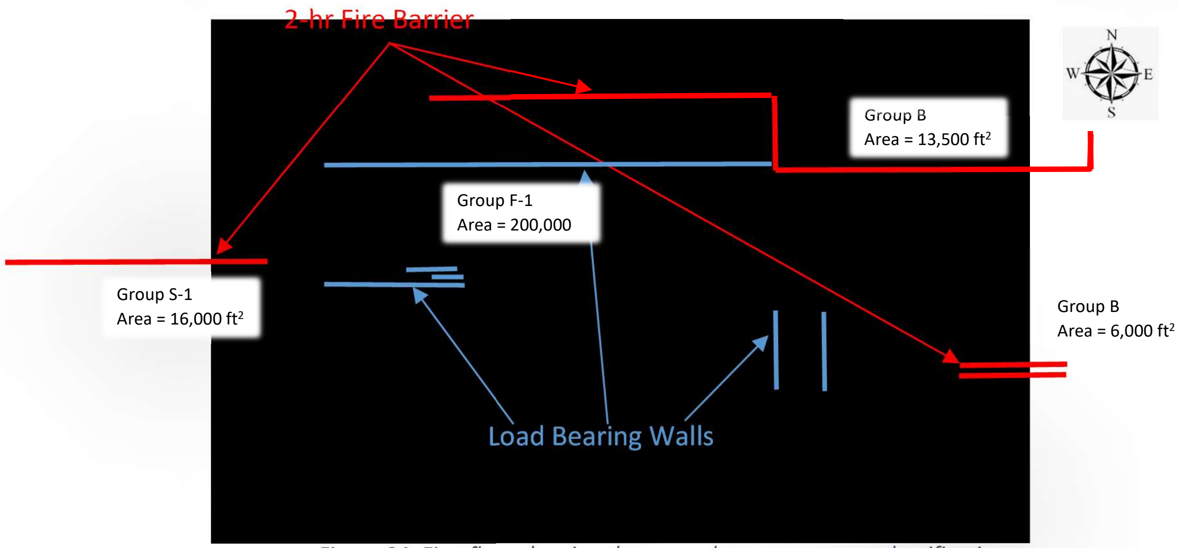


Figure 84: First floor showing the general area occupancy classifications.

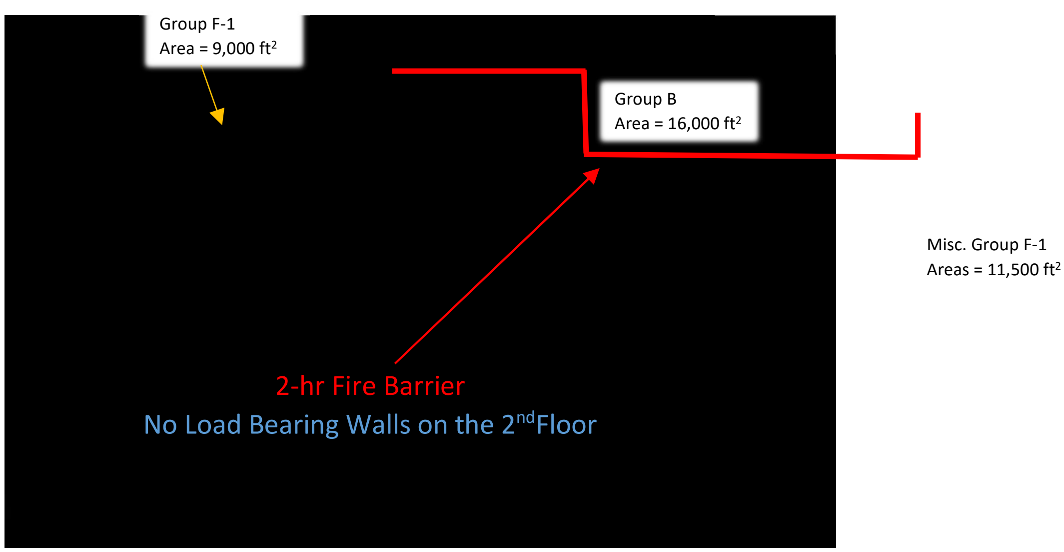


Figure 85: Second floor showing the general area occupancy classifications.

Fire Resistance Requirements
This building complex has no fire rated construction except for the fire barriers previously described in Figure 84 and Figure 85. Except for minor load bearing walls, the structure is supported by steel columns and beams. There is no structural member protection. As this structure is managed as Type VB construction, there is no code driven requirement for fire separation for structural members.

Fire Safety Strategy
The legacy nature of the building's original construction in 1959 did not focus on a structural fire safety strategy that involved either compartmentation or fire resistance for the structural members. This structure used non-combustible construction as much as was reasonably practical for the time. The suppression and manual alarm systems were added later in the building's life. New additions to this building did utilize Type IIB construction but did not include compartmentation and fire separation practices. The combustible portion of the live load for this structure is minimized to ensure fire cannot spread. The facilities management policies focus on ensuring overall combustible loading is kept reasonably low without impacting operations.

The bulk of the area for this building includes large open high bays with ceilings between 25' and 97'. These large areas have administrative controls to minimize the storage of combustible materials. The open nature of these atrium areas restricts typical fires from flashover but could result in traveling fires depending on the geometry of the combustible fuel. Trucks can also be brought into the building for offloading mostly non-combustible cargo. These trucks introduce a large combustible load in terms of fuel and vehicle components such as rubber and upholstery. Administrative controls require such vehicles to have at least a 10' clearance away from combustibles and require fire extinguishers to be staged near the trucks.

PERFORMANCE BASED FIRE BARRIER ANALYSIS

Due to the extreme size of the ACME Building both in terms of area and height, additional analysis is performed on the survivability of this structure.

Three potential worst-case fires that may impact the structure are defined as part of this structural fire analysis. These include the following:

1. A pool fire in the west high-bay location due to a leaking fuel tank on a truck parked within the building.
2. A traveling fire burning through PNNRA-117.
3. A first-floor compartment (office) fire that results in flashover.

The building structure relies on a frame that is repeated throughout the building's structural skeleton. Although each of the fire scenarios are for separate locations, the same general type of structural element with the same approximate load distribution can be examined as a bounding member for evaluating purposes. The load calculation and beam characterization are only performed for the first Design Basis Fire (DBF). This is because of the symmetry of the structural design of this building. The beam/girders being analyzed are mounted in such a way that gas flows can access all sides, which provides hot gasses access to the whole beam for analysis purposes. Therefore, temperature gradients between the top and the bottom of the beams and girders are not being considered. Additionally, the influence of stresses associated with lateral expansion of the beam/girder are not analyzed for the DBFs due to redundancy in the structural design. The primary feature of failure being analyzed in the three DBFs below is heat weakening of the material resulting in loss of strength and subsequent deflection and collapse.

The following three DBFs are analyzed for the impact fire has on structural collapse. Additional DBFs are included in this report for separate areas of analysis after this section that includes fire alarm activation, means of egress time evaluations, suppression activation, and characterized smoke behavior.

DBF 1

The first DBF is represented by a truck in the west high-bay area that is parked too close to the north side of this location and is accidentally struck by equipment resulting in a 20-gallon diesel spill that migrates near structural steel, which is three meters above the concrete floor at the north edge of the high bay. A reasonable worst-case estimate for this diesel pool spill on the ground can be approximated to cover 26 m^2 (280 square feet). This maximum area of coverage is based upon the general blockages on the floor in this area that will limit the spread of liquids on the ground, and an estimated worst-case spill thickness of 2.9 mm as specified on Page 2,558 in the Handbook of Fire Protection Engineering 5th edition, Reference (h). Any additional HRR from wood crates will be considered included with the heat of combustion of the diesel. A traveling fire associated with fire spreading through combustible storage may occur in this area but is not likely for this fire scenario. Combustible crates do exist on islands in this area which could ignite; however, the likelihood of this occurring is not examined for this pool fire due to its short duration. The assumption of an HRR represented only by 280 ft^2 of diesel fuel is reasonable for this analysis.

A steady state scenario of a diesel pool fire will be used as the input with a constant HRR. It is assumed that after 20 gallons of fuel are consumed, this fire will either be controlled, or the fuel leak will be stopped or exhausted. This steady-state fire at the maximum HRR is considered a worst-case probable bounding scenario and utilizes conservative assumptions. Some of these conservative assumptions include the constant HRR and instantaneous ignition of the entire pool.

The ground cools the combustible liquid in the pool as the depth of the pool decreases. This results in a lowering of the HRR over time. The ground-cooling effect is being ignored in this analysis for added conservatism. Combustible liquids have a specific velocity of flame spread that delays ignition for the entire pool, which is being conservatively ignored. Over time, the area of the pool fire will reduce. This is because the boundaries of the pool are thinner than the middle of the diesel pool and will burn through the fuel faster resulting in a lowering of the radius of the pool as the fire burns. This difference in pool thickness is conservatively ignored to ensure maximum HRR.

DBF 1 Fire Assumptions

1. A pool fire of constant HRR will be used with diesel (fuel oil) as the fuel source. The pool depth will not cause a cooling effect from the ground that will result in a declining HRR.
2. The high HRR will result in no stratification within the main high bay (approximately 60’ high ceiling). The effect on the structural members will be achieved by mimicking a three-meter (ten-feet) ceiling height due to obstacles that could result in a worst-case ceiling jet affecting girders

in this area. This is a highly unlikely scenario and provides a bounding example for how this fire will affect the structure.

3. The maximum HRR will be reached immediately with no consideration for flame spread within the pool.
4. Any combustible components of the shipping truck or adjacent combustible packaging will be appropriately represented by the HRR of the diesel pool fire.
5. The area of the pool fire will remain constant at 280 ft^2 (26.0 m^2).
6. A total of 20 gallons of diesel will represent the fuel loading.
7. The worst-case location is a structural member that is 10' horizontally away and 10' above the fire location. This location has a greater exposure than the overhead ceiling trusses due to the approximate 60' height of the high-bay and the air entrainment resulting in a cooler ceiling jet at the ceiling location.

DBF 1 Variables

A	= *Cross sectional area of structural component*	
A_f	= *Area of pool fire*	
c_{p-s}	= *Steel Heat Capacity (460 J/kg-K)*	
D	= *Live Load (lb/ft^2)*	
E	= *Young's Modulus (29,000,000 PSI)*	*A992 Steel*
$E_{(T)}$	= *Young's Modulus at Temperature*	
F/V	= *Section Factor*	(Steel Heated perimeter over cross sectional area)
f_y	= *Yield strength of structural member (50,000 PSI)*	*A992 Steel*
$f_{y(T)}$	= *Yield strength of structural member at specific temperature*	
H	= *Height where gas temperature is measured*	
Δh_c	= *Heat of Combustion*	
h_c	= *Convective Heat Transfer Coefficient (20 W/m^{2}K)*	*Typical for smoke plume velocity*
I	= *Area moment of inertia (in^4)*	
L	= *Length of beam for stress determination (ft)*	
LL	= *Live Load (lb/ft^2)*	
M_u	= *Applied Moment (lb-ft)*	
$\dot{m}''$	= *Burn rate of fuel*	
$\dot{m}''_\infty$	= *Optimal burn rate of fuel*	
P	= *Point Load (lb)*	
$\dot{Q}$	= *HRR (kw)*	
Rad	= *Distance between fire and location of interest (m)*	
R	= *Resultant Force (lb)*	
SG	= *Specific Gravity of diesel (0.85)*	
t	= *Time (s)*	
Δt	= *Time Step (s)*	
t_f	= *Time for 20 gallons of diesel to completely burn at the maximum HRR*	
T	= *Temperature*	
T_{cj}	= *Temperature of ceiling jet (°C)*	
T_S	= *Surface temperature of structural member (°C)*	
T_∞	= 20° C (*Ambient temperature)*	

V = *Volume of Fuel*
W_D = *Dead Load (lb/ft)*
W_L = *Live Load (lb/ft)*
W_t = *Total Load (lb/ft)*
Δx = *Deflection*
Z = *Height of smoke layer represented as 6' above the worst-case walking surface*
Z_X = *Plastic Modulus (in^3)*
δ_f = *Fuel Thickness*
ε = *Emissivity (1)* — *Conservative assumption*
ρ_s = *Steel Density (7,850 kg/m^3)*
σ = *Stefan Boltzman Coefficient ($5.67^{(-0.8)}$ kW/m^2-K^4)*
Φ = *Structural Load factor* (0.9 for design; 1 for fire analysis) — *Structural deprecation factor*
ΦM_N = *Maximum allowable moment*

CALCULATING BOUNDING CONDITIONS FOR FIRE

Additional Variable Values

δ_f = 2.9 mm (0.113 in)	*Pg. 2,558 of Reference (h)*
V = 20 gallons (2.67 ft^3)	
A_f = 2.67 ft^3 / (0.113 in/ 12 in/ft)	
A_f = 280 ft^2 (26 m^2)	*Assumption 5*
$\dot{m}'' = \dot{m}''_\infty$	*Equation 20 (Eq. 65.20 Reference (h))*
$\dot{m}'' = \dot{m}''_\infty$ ~~$[1-e^{-kbD}]$~~	*$[1-e^{-kbD}]$ = 1.0 for D > 2.6 m*
$\dot{m}'' = \dot{m}''_\infty$ = 0.035 kg m^{-2} s^{-1}	*Table 26.21 Reference (h)*
$\dot{Q} = \dot{m}'' * A_f * \Delta h_c$	*Equation 22 (Eq. 65.24 Reference (h))*
Δh_c = 39.7 MJ kg^{-1}	*Table 26.21 Reference (h)*
H = 10' (3 m)	*Assumption 7*
R = 10' (3 m)	*Assumption 7*

Calculating Worst-case Time (t_f) to Burn the 20 gallons Resulting in the Highest HRR

t_f = V * SG * 8.33 lbs/gallon / 2.21 lbs/kg / ($\dot{m}''$ * A_f)
t_f = 20 gallons * 0.85 * 8.33 lbs/gallon / 2.21 lbs/kg / (0.035 kg m^{-2} s^{-1} * 26 m^2)
t_f = 70 seconds

Calculating the Maximum HRR ($\dot{Q}$)

$\dot{Q} = \dot{m}'' * A_f * \Delta h_c$
$\dot{Q}$ = 0.035 kg m^{-2} s^{-1} * 26 m^2 * 39.7 MJ kg^{-1} * 1000 kW/MW
$\dot{Q}$ =36,127 kW

Calculating the Gas Temperature at the Nearest Structural Member

<u>Alpert's Ceiling Jet Correlations</u>

$T_{cj} - T_\infty = 16.9\ \dot{Q}^{2/3} / H^{5/3}$	for Rad/H $\leq$ 0.18	*Pg. 1,324 Reference (h)*
$T_{cj} - T_\infty = 5.38/H * (\dot{Q}/R)^{2/3}$	for Rad/H > 0.18	*Pg. 1,323 Reference (h)*

Rad / H = 3 m / 3 m = 1
T_{cj} = 5.38 / 3 m * (36,127 kW/3 m)$^{2/3}$ + 20°C; T_{cj} = 960° C

STRUCTURAL analysis

Equations for Yield Stress at High Temperatures

$f_{y(T)} = [1 + T / (900 \ LN \ (T/1750))] * f_y$ — $f_{y(T)}$ for Temp for 0 < T ≤ 600° C; Page 1,913 Reference (h)

$f_{y(T)} = [(340-0.34T)/(T-240)] * f_y$ — $f_{y(T)}$ for Temp for 600° < T ≤ 1000° C; Page 1,913 Reference (h)

$E_{(T)} = [1 + T / (2000 \ LN \ (T/1150))] * E$ — Young's Modulus modified for Temp for 0 < T ≤ 600° C; Pg. 1,913 Reference (h)

$E_{(T)} = [(690-0.69T)/(T-53.5)] * E$ — Young's Modulus modified for Temp for 600° < T ≤ 1000° C; Pg. 1,913 Reference (h)

Calculating Structural Loads Under Fire Conditions

$W_{t,f} = 1.2W_D + 0.5 \ W_L$ — CalPoly handout: modified structural formula for fire failure

$\Phi M_{N(T)} = \Phi * f_{Y(T)} * Z_X$ — CalPoly handout

Load Evaluation

Structural loads are distributed perpendicularly to the beams. The resultant loads on the girder are all point loads.

D includes the weight of the beams for this analysis in addition to the distributed dead load.

D = 40 PSF

LL = 40 PSF

Tributary Width (W) = 10'

W_D = 40 PSF * 10'

W_D = 400 lb/ft

W_L = 40 PSF * 10'

W_L = 400 lb/ft

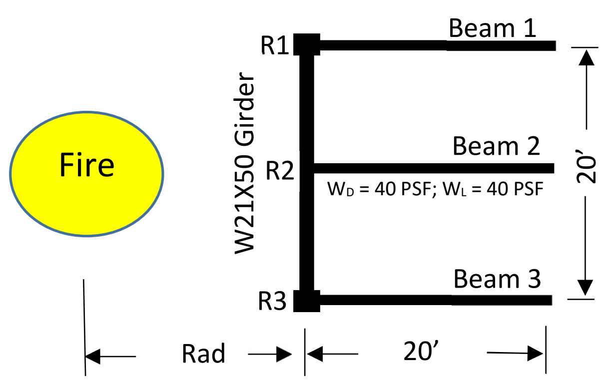


Figure 86: Plan view of the pool fire example used for DBF 1.

Factored Distributed Load

$W_{T,f}$ = 1.2 * 400 lb/ft + 0.5 * 400 lb/ft

$W_{T,f}$ = 680 lb/ft

Unfactored Distributed Load

$W_{T,u}$ = 400 lb/ft + 400 lb/ft

$W_{T,u}$ = 800 lb/ft

Resultant Forces on Girder due to Beam Loads (R = L * W) *(Applied Load Length on Girder = 20')*

Factored Load	**Unfactored Load**
$R1_f = R2_f = R3_f$ = 20' * 680 lb/ft = 13,600 lb	$R1_U = R2_U = R3_U$ = 20' * 800 lb/ft = 16,000 lb

The girder is represented by a W21X50 I-Beam

Properties for the Estimated W21 X 50 Girder Size

I_x = 984 in^4; Z_x = 110 in^3; A = 14.7 in^2; b_f = 6.53 in; t_w = 0.380 in; d = 20.83 in — AISC Beam Properties

Moment Stress

$M_U = R * L / 4$ — *Applicable beam formula* (CalPoly handout)

Factored Moment
M_U = 13,600 lb * 20' /4; M_U = 68,000 ft-lb

Deflection
Unfactored Initial Deflection
$\Delta x = R * L^3 / (48 * E * I)$ *Applicable beam formula* (CalPoly handout)
$\Delta x = 16{,}000 * (20 \text{ ft} * 12 \text{ in/ft})^3 / (48 * 29{,}000{,}000 \text{ lb/in}^2 * 894 \text{ in}^4)$
Δx = 0.18"
Permissible deflection (Δx_p) during a fire
$\Delta x_p = L/20$ *Applicable beam formula* (CalPoly handout)
Δx_p = 20 ft * 12 in/ft /20
Δx_p = 12"

Failure occurs when Δx in a fire ($\Delta x_f = R * L^3 / [48 * E_{(T)} * I]$) is greater than Δx_p or when $\Phi M_{N(T)} < M_u$:
$\Phi M_{N(T)}$ < 68,000 ft-lb
Δx_f > 12"

$\Phi M_{N(T)}$ is dependent on $f_{Y(T)}$ and Δx_f is dependent on $E_{(T)}$. These variables depend on temperature. These calculations require an iterative solution using Excel.

The Heat Transfer Equation into the Steel Beam to be Solved Iteratively for T_{cj} is shown below. This equation for T_S is applied to this and the next two DBF analyses, where each of these DBF sections use this equation to calculate the heat of the steel member being analyzed. The superscript values of "t" and "t+1" represent steps in the iteration process.

$T_S^{t+1} = (F/V) * (\Delta t/(\rho_s * c_{p\text{-}s}) * [h_c * (T^t_{cj} - T^t_s) + \sigma * \varepsilon * (T^t_{cj}{}^4 - T^t_s{}^4)] + T^t_s$ CalPoly handout
$F/V = (3 * b_c + 2 * d - 2 * t_w) / A$; CalPoly handout
F/V = (3 * 6.53" + 2 * 20.83" – 2 * 0.38") / 14.7 in^2
F/V = 4.1 in^{-1} (160.48 m^{-1})

Figure 87 and Figure 88 show the applied deflection for DBF 1 and the maximum available moment as the steel girder heats up. Table 4 below these images shows the data involved in these iterative calculations using the formulas above. The Girder reaches approximately 450° C by the time the fuel burns out. This temperature is insufficient to reduce the yield strength and Young's Modulus enough to cause structural collapse.

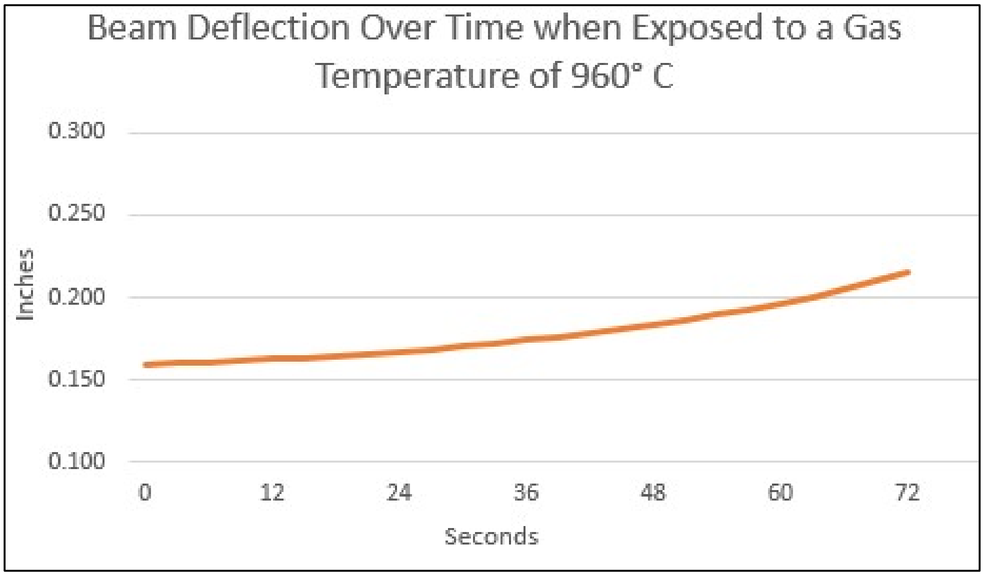


Figure 87: Deflection over time as the girder is heated for DBF1.

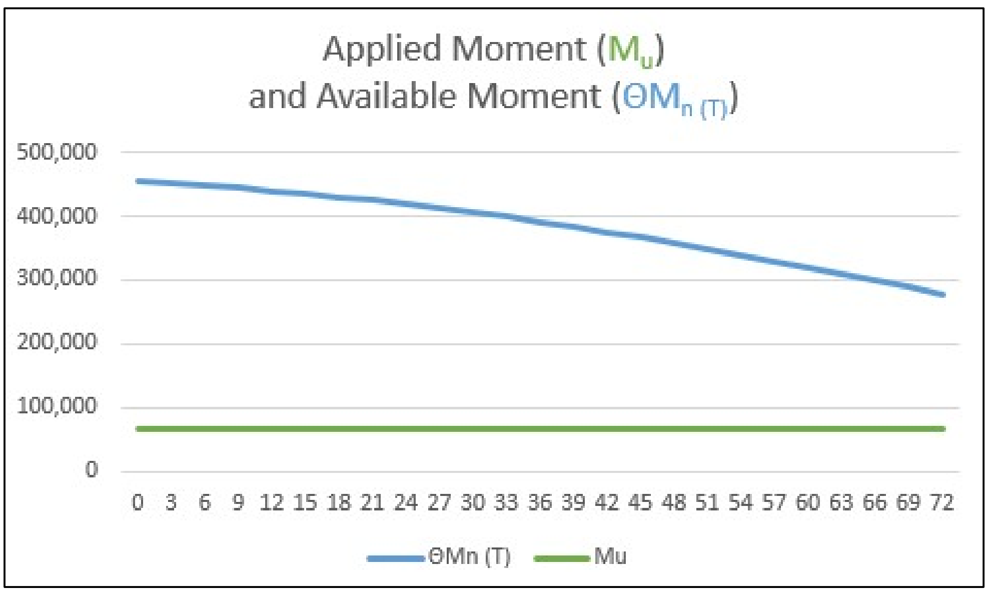


Figure 88: Applied and available moment for DBF 1.

Table 4: Data used in calculating the deflection and available moment as the girder heats up.

	Time (s)	Steel Temp (°C)	Unfactored Deflection (in)	Yield Strength (PSI)	Young's Modulus (PSI)	Allowable Moment (ft-lb)
Gas (T)	t	T_s	Δx_f	$f_{y(T)}$	$E_{(T)}$	$\Theta M_{n\,(T)}$
960	0	20	0.160	49,752	28,928,427	456,056
960	3	40	0.160	49,413	28,827,739	452,955
960	6	60	0.161	49,017	28,706,865	449,318
960	9	80	0.162	48,570	28,568,112	445,225
960	12	99	0.163	48,078	28,412,477	440,718
960	15	119	0.164	47,544	28,240,396	435,820
960	18	138	0.165	46,969	28,052,004	430,548
960	21	158	0.166	46,354	27,847,244	424,913
960	24	177	0.167	45,701	27,625,933	418,922
960	27	196	0.169	45,009	27,387,788	412,581
960	30	216	0.170	44,279	27,132,456	405,894
960	33	235	0.172	43,513	26,859,522	398,865
960	36	254	0.174	42,709	26,568,524	391,496
960	39	272	0.176	41,868	26,258,957	383,790
960	42	291	0.178	40,991	25,930,284	375,750
960	45	309	0.181	40,078	25,581,936	367,377
960	48	328	0.183	39,128	25,213,324	358,676
960	51	346	0.186	38,144	24,823,835	349,649
960	54	364	0.189	37,124	24,412,846	340,301
960	57	382	0.193	36,069	23,979,722	330,636
960	60	399	0.196	34,981	23,523,822	320,660
960	63	417	0.200	33,859	23,044,506	310,379
960	66	434	0.205	32,705	22,541,141	299,800
960	69	451	0.210	31,520	22,013,102	288,931

DBF 1 Conclusion

A worst-case fire due to a diesel spill on the north side of the west high bay does not generate enough energy to reduce the nearest load bearing girders sufficiently to cause damage or otherwise result in structural failure, neither does this fire result in girder deflection exceeding the allowable values.

Although this DBF analyzes the heat transfer to nearby structural members, it does not analyze the effects of fuel fires directly around columns. It is remotely possible that large volumes of fuel could spill and possibly pool around columns; however, this event is improbable for this DBF due to other complications. DBF 1 considers the worst-case probable fire with a single event resulting in a fuel spill that includes a truck parked in an unusual location. For an improbable event to occur, such as the pooling of fuel around a column, multiple events would be required to occur simultaneously, such as the piercing of a fuel tank when it is parked in a non-permitted area. This is because obstacles between the normal parking area and any adjacent columns would block the natural spreading of fuel from a spill. This analysis also makes assumptions in calculating the ceiling jet temperature at a short 10-foot height which is extremely conservative at this location because of the 60-foot ceiling.

If a pool fire such as this did occur around a steel column, the heat transfer into the steel would be rapid and could very likely result in that column losing its strength resulting in partial collapse. Past research with full-scale mock-up fire tests have shown collapses from losing a single structural member will likely not occur due to the redundancy in the structure. A structural collapse from a fuel spill related fire at this location is improbable.

DBF 2

The Group S-1 area in PNNRA-117 is a large high-bay with sloped ceilings. This 16,000 ft^2 area at the southwest of the ACME Building is likely to remain fuel limited while burning due to the large open area. This will result in a traveling fire that will move through the material as the combustibles are consumed rather than a flashover fire common in smaller compartments. This will result in the structural members experiencing a longer exposure at lower temperatures.

The Traveling Fire Methodology (TFM) was defined after the events of the World Trade Center #7 collapse, where this building burned more than eight hours prior to reaching structural failure. This unique situation occurred due to a lack of suppression functionality and the inability of the emergency response crews to reach this location. This TFM style of fire burns slower but has a longer duration where the energy can be transferred into the structural members resulting in failure. This type of analysis is being applied in this situation as a bounding condition in the event of a significant failure in the ability to deliver water to the suppression system combined with a problem with first response activities for this building. This could occur in the event of seismic activity or terrorist actions.

This portion of the building has combustible loading due to mostly non-combustible stored items with combustible packaging (Class II commodity), although it more closely reflects Class III commodities due to plastic contents. There is a wider separation between combustibles than typical warehouse environments, which reduces the rate of fire spread. This warehouse is approximately 80-feet x 200-feet (24.4 m X 61 m). It has a fire rated overhead door to the north that will automatically close when smoke is detected and has a ceiling that is peaked on the north side. The applicable height used in this TFM analysis for this sloped warehouse ceiling is 25’ (7.6 m).

A worst-case situation will occur when a fire starts on one of the narrow ends of the building and moves toward the other end. This situation allows for maximum preheating of the structural members being analyzed prior to the member being directly adjacent to the source of combustion. The beam being analyzed is chosen at 55 m from the other end of the building. This provides maximum time for preheating the girder prior to the flame being under the structural member. This Traveling Fire Methodology is applied in this report per the instructions as found in the journal article: *Improved Formulation of Travelling fires and Application to Concrete and Steel Structures,* June of 2015, Reference (i).

DBF 2 Variables

The following variables and values will be used in addition to the variables used for DBF 1:

$A_f = 148.84\ m^2$	*(Surface area of burning fuel)*	*($A_f = L * W * L^*$)*
$H = 7.6\ m$	*(Height of the compartment for this analysis)*	
$L = 61\ m$	*(Length of the compartment)*	
$L^* = 10\%$	*(Estimated percent of floor area on fire)*	
$\dot{Q} = 74{,}420\ kW$	*(Size of fire)*	*($A_f * \dot{Q}''$)*
$\dot{Q}'' = 500\ kW/m^2$	*(Estimated HRR per unit area)*	
$T_{nf} = 1{,}200°C$	*(Maximum gas temperature)*	
$T_A = 20°C$	*(Ambient room temperature)*	
$W = 24.4\ m$	*(Width of compartment)*	
$q_f = 315\ MJ/m^2$	*(Estimated fuel loading by inspection)*	
$S = 0.0097\ m/s$	*(Fire spread rate)*	*($S = L^* * L / t_b$)*
$t_b = 630\ s$	*(Area of combustion burn time)*	*($q_f * 1000/ \dot{Q}''$)*
$t_{total} = 6{,}930\ s$	*(Total fire duration)*	*($t_b * (1/L^*+1)$)*

The same sized girder applied load and the same heat transfer equations are applied for DBF 2 as were applied for DBF 1. The only difference is the time for exposure and the temperature of the gas surrounding the I-beam.

The following graph shows the temperature profile of the steel girder in comparison to the temperature of the gas flowing past it.

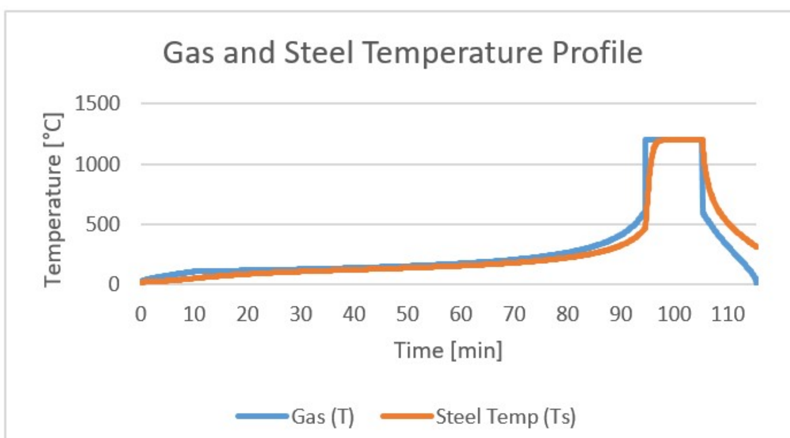


Figure 89: Graph of gas and steel temperature due to a traveling fire in the Group S-1 area.

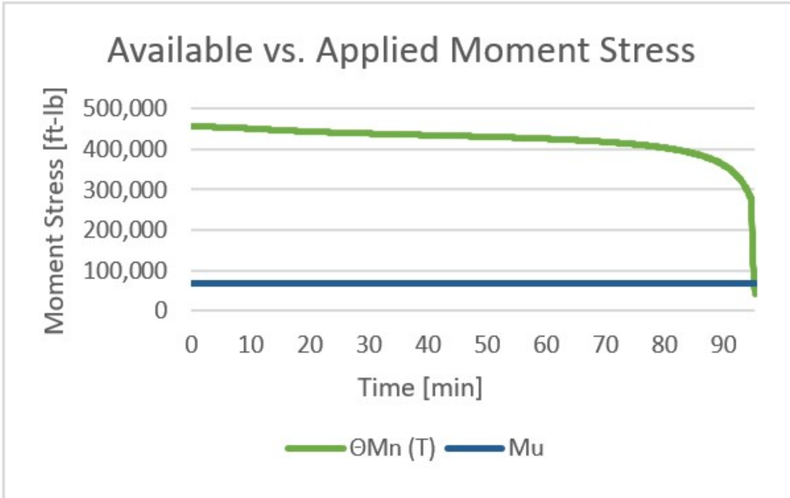


Figure 90: Available ($\Theta M_{n(T)}$) and applied (M_u) moment stress.

DBF 2 Conclusion

Although there is a minor time-lag, the gas temperature, and the temperature of the steel girder track closely due to the high thermal conductivity of steel and the lack of insulation. Failure of the girder due to both deflection (Δx_f > 12") and yield ($\Theta M_{n(T)}$) from the applied moment load would both occur at approximately 96 minutes with this scenario. The conclusion from reviewing these two graphs is that the girder will fail anytime this traveling fire is directly under it due to the high final temperature of the steel, which occurs because of the rapid heat transfer into the steel and the long duration of the fire while under the structural member. Structural failure could occur if suppression and emergency responders were both unavailable to control a fire within this warehouse location. The difference between the conclusions of DBF 1 and DBF 2 is that the first design fire analysis used a pool fire with a short duration. DBF 2 relies on a long burning fire that results in higher amounts of heat transfer into the member, which is why DBF 2 results in possible structural collapse. Although a collapse is possible with a TFM in this warehouse if left to burn, it is not likely as suppression and manual firefighting is available to control a fire unless an extreme situation occurred. A TFM is also not likely to occur due to the separation of combustibles in this area. This topic will be discussed further in this report.

DBF 3

This fire scenario involves a first-floor office on the north side of the building complex. This compartment is modeled as a 3 m X 4.5 m X 3 m room with a single door that is 2.1 m high and 0.9 m wide. The combustible loading (e_f) is estimated to be 570 MJ/m^2. The Heat of Combustion (ΔH_c) of the combustible loading is approximately 21 MJ/kg.

The same beam size used in DBF 1 and DBF 2 shall be applied to this structure, as similar structural members are used throughout this building. This girder is above a false ceiling and is near the exterior wall. The same dead and live load shall be applied to it as in DBF 1 and DBF 2. This girder has no fire rated protection. It is assumed that the ceiling panels will quickly fail during a flashover in this compartment, so any effect that the ceiling panels have on heat transfer will be minimal.

This analysis will use the Margaret Law Design Methodology to calculate the gas temperature profile that the steel structural members in the room will be subject to during a compartment fire.

The following variables and equations will be used in addition to the heat transfer and structural formulas defined in the DBF 1 section.

$t_{BO} = M_f / R_b$ (Time to Burnout) (CalPoly Handout)
$R_b = 0.1A_O H_O^{1/2}$ (Burning Rate [kg/s]) (CalPoly Handout)
$A_O = 1.9\ m^2$ (Area of Opening)
$H_0 = 2.1\ m$ (Height of Opening)
$R = 0.1 * 1.9\ m^2 * (2.1\ m)^{1/2}$
$R_b = 0.28\ kg/s$
$M_f = e_f * A / \Delta H_c\ (kg)$ (Mass of Fuel) (Structural Design for Fire Safety, 2nd Edition, Reference (j) Eq. 3.12)
$e_f = 570\ MJ/m^2$
$\Delta H_c = 21\ MJ/kg$
A (area) = 3 m * 4.5 m
$M_f = 570\ MJ/m^2 * (3*4.5)\ m^2 / 21\ MJ/kg$
$M_f = 366\ kg$
$t_{BO} = 366\ kg / 0.28\ kg/s = 1{,}307$ seconds
$t_{BO} = 22$ minutes

Since $t_{BO} < 60$ minutes, cooling phase shall be 10° C / minute. (CalPoly Handout)

Maximum Temperature Evaluation:
$T_{Max} = 6000 * (1-e^{-0.1\Omega}) / \Omega^{1/2}$ (Maximum Temperature [°C]) (Reference (j) Eq. 3.19)
$\Omega = (A_t - A_v) / (A_v H_v^{1/2})$ (Reference (j) Pg. 54)
$A_t = 2*(L * W + L * H + W * H)$ (Total interior surface area [m²]) (Reference (j) Eq. 3.17c)
L = 4.5 m (Room Length)
W = 3 m (Room Width)
H = 3 m (Room Height)
$A_t = 2* (4.5 * 3 + 4.5 * 3 + 3 * 3)$
$A_t = 72\ m^2$
$A_V = O_W * O_H$ (Area of opening)
$O_W = 0.9\ m$ (Width of opening)
$O_H = 2.1\ m$ (Height of opening)
$A_V = 2.1\ m \times 0.9\ m$;
$A_V = 1.9\ m^2$
$H_V = 2.1\ m$ (Height of opening) (Reference (j) Eq. 3.17a)
$\Omega = (72\ m^2 - 1.9\ m^2) / (1.9\ m^2 * (2.1\ m)^{1/2})$
$\Omega = 25.5\ m^{-1/2}$
$T_{Max} = 6{,}000 * (1-e^{-0.1 * 25.5}) / 25.5^{1/2}$

The bounding values for the gas temperature using the Margaret Law Methodology are as follows:
T_{Max} = 1,095° C
t_{BO} = 22 minutes
Decay = 10° C / minute

The Margaret Law Methodology is a bounding condition. It does not reflect an actual gas temperature profile but reflects the temperature that would produce a similar heat transfer that would occur in a flashover compartment fire. The following graph shows the Margaret Law Methodology temperature and time profile plotted against the steel temperature of the girder that is part of this problem.

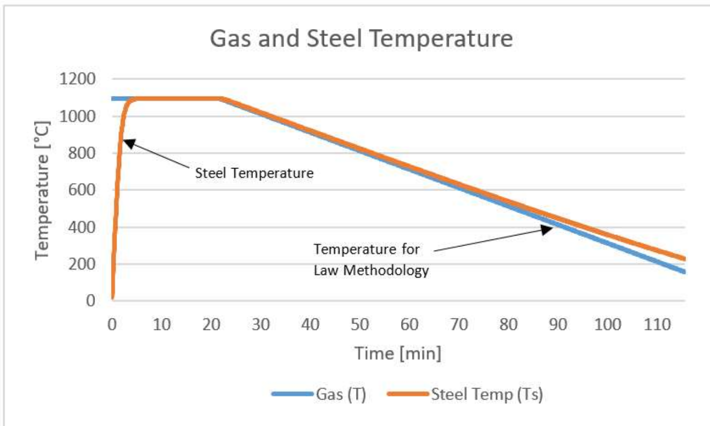


Figure 91: Margaret Law Methodology gas and steel temperature.

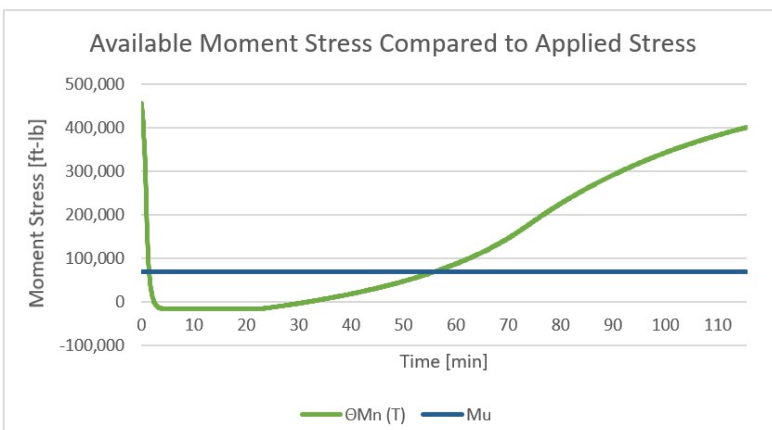


Figure 92: Available ($\Theta M_{n(T)}$) and applied (M_u) moment stress.

DBF 3 Conclusion

Figure 92 indicates that the exposed beam in an unsprinklered compartment would fail because of its lack of applied fire protection material in flashover conditions. This 1,095° C initial applied gas temperature results in failure in both deflection (Δx_f > 12”) and yield ($\Theta M_{n(T)}$) from the applied moment load. This example utilizing the Margaret Law Methodology does not represent a real fire. It represents a correlation between gas temperature due to the compartment dimensions and fuel loading that corresponds with the likely heat transfer this member receives. The actual resistance time of this girder to failure would be longer in a real fire as the gas temperatures would not immediately reach the maximum 1,095° C this simulation specifies.

Notwithstanding the small length of time specified before failure using this theory, this girder will fail if suppression is not provided to the fire in this room because the high compartment temperatures will weaken the material to the point that it cannot hold up the applied load.

General observations from these three DBFs

Each of the three structural members evaluated have no fire rated protection. This analysis relied on heat transfer into the steel and calculational methods defined by the Society of Fire Protection Engineering (SFPE) to estimate the yield strength and Young's Modulus at specific temperatures.

Failure of the members in DBF 2 and DBF 3 was due to inadequate strength to resist the applied bending moment due to a lack of fire protective insulation protecting the member. The member in DBF 1 would fail with a greater pool fire from a larger diesel fuel spill, which is possible but unlikely to occur at that location.

Fire rating as defined within Reference (b) is based upon the structural member's performance to discrete temperature and time points defined by ASTM E119 which is shown in Figure 93:

Time (min)	ASTM E119 temperature (°C)
0	20
5	538
10	704
30	843
60	927
120	1010
240	1093
480	1260

Figure 93: ASTM E119 temperature and time points.

The fire rating for steel members that corresponds to the above set of points is defined by formulas for both non-protected and protected steel columns. As the structural analysis involved a girder that had the gas temperature on all four sides, the formulas for columns are applied as reviewed in the next section.

DBF 1-3 Equivalent Rating without Applied Fire Protective Insulation

The fire rating of the girder used for the three DBFs above with no added insulative protection is determined as follows:

$R_r = 10.3\,(W/D)^{0.7}$ (Fire rating in minutes) Reference (h) Table 53.3

W = 50 lbs/ft (Weighted steel per linear foot)

$D = 4 * b_f + 2 * d - 2 * t_w$; D = 4 * 6.53" + 2 * 20.83" – 2 * 0.38" Reference (h) Fig. 53.10

D = 67"

$R_r = 10.3\,(50/67)^{0.7}$

R_r = 8.39 minutes

This 8.39-minute rating is the expected duration of the W21X50 structural member if exposed to the ASTM E119 temperature profile as shown in Figure 93. The results from DBF 2 and DBF 3 show an earlier failure than 8.39 minutes when the girder is directly exposed to higher temperatures. This is because the ASTM E119 standard fire time rating is based upon a growing temperature profile that is initially at ambient (20° C). At 8.39 minutes, the ASTM E119 profile is approximately 650° C when failure is predicted. DBF 2 exposed the girder to 1,200° C gas temperatures when the fire moved underneath it. DBF 3 exposed the girder to 1,095° C gas temperatures initially. In both the DBF 2 & 3 examples, once these higher temperatures were being exposed to the girder, failure was predicted very quickly.

DBF REVIEW WITH FIRE RATED MEMBERS

The following analysis revisits DBF 1-3 by identifying the performance of the girders if a 2-hour layer of fire protection insulation was applied to the structural members.

A W21X50 beam would require sprayed on mineral fiber with the following thickness (h) for 2-hr protection:

$h = 120 \text{ minutes} / [C_1 (W/D)+C_2]$ Reference (b) Eq. 7-13

$C_1 = 63; C_2 = 42$ See NFPA Fire Protection Handbook, 20th edition, Reference (k), Page 19-47 for C_1 and C_2

h = 120 / [63 * 50/67 + 42]

h = 1.3" (0.033 m)

Heat Transfer Equation for Insulated Steel Beam for Iterative Solution to Determine Steel Temperature

$T_S^{t+1} = (F/V) * (k_i/d_i) * [\Delta t * (T^t_g - T^t_s) / (\rho_s * c_{p-s} + 0.5(F/V) * (d_i * \rho_i * c_{p-i}))] + T^t_s$ CalPoly handout

T_S^{t+1} = **Temperature of PROTECTED steel** CalPoly handout

k_i = Thermal conductivity of insulation (0.12 W/m-K) CalPoly handout

d_i = Insulation Thickness (m)

ρ_i = Insulation Density (300 kg/m^3) CalPoly handout

c_{p-I} = Insulation Heat Capacity (1,200 J/kg-K) CalPoly handout

Significant improvements can be shown in the structural performance of the girder used in DBF 1-3 by applying the above heat transfer formula to the same girder used in DBF 1-3, where the girder now has a thickness of 1.3" of fire protective insulation for a 2-hour rating. Figure 94 through Figure 96 show the girder performance for each of the three DBF scenarios if insulation is applied.

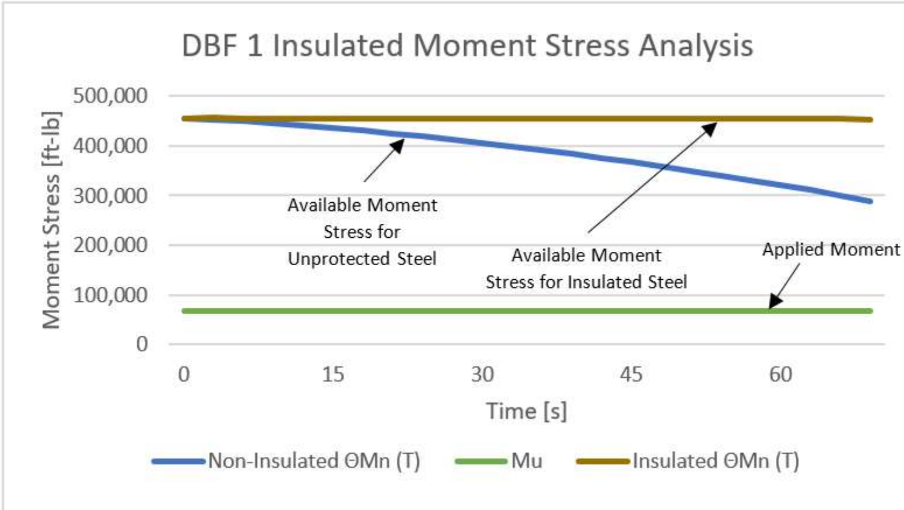


Figure 94: Results for DBF 1 with the 2-hr rated protected girder.

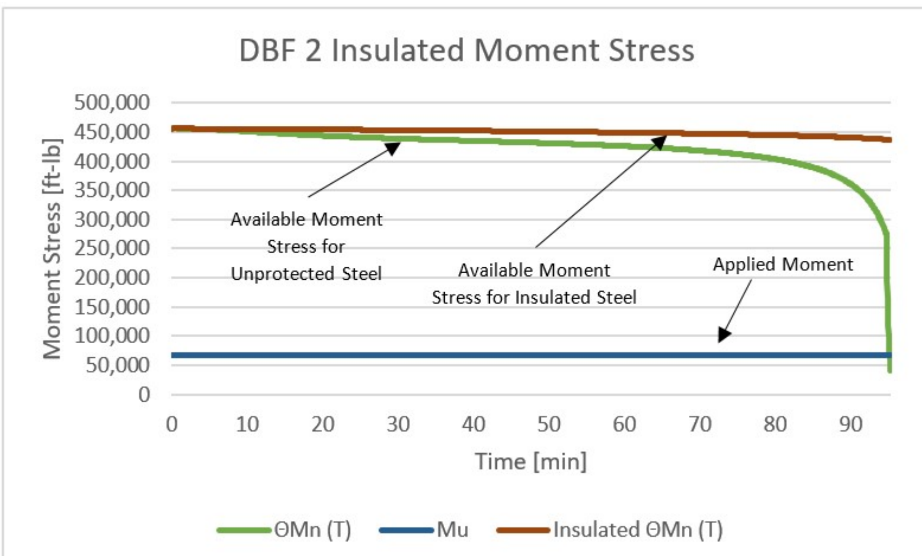


Figure 95: Results for DBF 2 with the 2-hr rated protected girder.

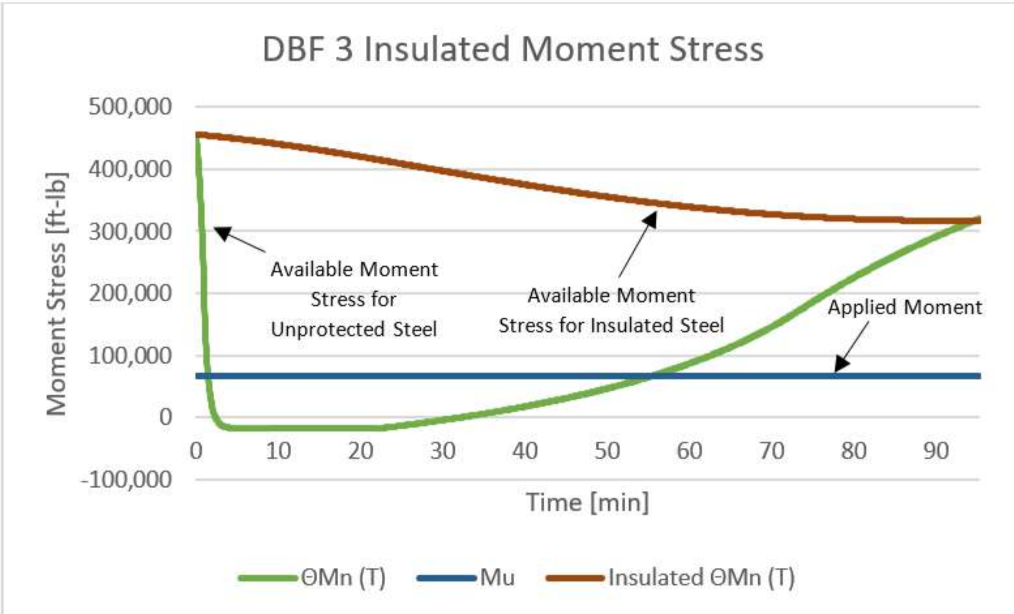


Figure 96: Results for DBF 3 with the 2-hr rated protected girder.

Adding the 2-hour rated insulation thickness results in none of the DBF scenarios having structural failure. The following tables show the reduced worst-case yield strength ($f_{y(T)}$), available moment ($\Theta M_{n(T)}$) and the safety factor. These data points are identified at the worst-case time for each scenario:

Table 5: Worst-case data for each DBF with insulation.

DBF 1

Worst-Case	$E_{(T)}$ KSI	$\Theta M_{n(T)}$ ft-Kip	Safety Factor
2-hr Protected	28,900	455	6.7

DBF 2

Worst-Case	$E_{(T)}$ KSI	$\Theta M_{n(T)}$ ft-Kip	Safety Factor
2-hr Protected	27,300	409	6.0

DBF 3

Worst-Case	$E_{(T)}$ KSI	$\Theta M_{n(T)}$ ft-Kip	Safety Factor
2-hr Protected	23,400	317	4.6

Recommendations

The above three DBFs show that the gas temperature that affects the structural steel is dependent upon the quantity of combustibles, the rate of combustion, and the distance that the fire is from the structural members. Minimizing combustibles is an important step to limit damage to a structure from a fire.

The time to burnout that was evaluated as part of DBF 3 for the Margaret Law Methodology was proportional to the quantity of combustibles. In this case, failure was estimated at approximately 10% of the burnout time. This suggests the structural members may not fail if the combustible live and dead load could be significantly reduced.

NFPA specifies (Reference (k) Pgs. 18-6/7) that 6-sided metal cabinets provide a 90% reduction factor to the combustible loading. Clearly, not all combustibles can be placed into such cabinets; however, it is reasonable to conclude that using file cabinets and metal office cabinets to store combustible items, such as books, paper and combustible equipment will reduce the overall length and intensity of the fire resulting in a higher likelihood of structural survivability.

DBF 2 relied on a traveling fire that spread in a warehouse storing mostly non-combustible material in combustible crates and packaging. Fire spread is proportional to the speed of combustion. That rate of combustion can be modified by applying a flame inhibitor to the combustible crating lowering the overall HRR. Furthermore, using separation between isolated islands of material in combination with the use of a flame inhibitor will significantly reduce the radiant thermal heat transfer from ignited combustibles to adjacent fuel. The combination of flame inhibitors and isolated storage techniques will result in a much lower HRR per unit area and a likelihood for self-extinguishment if a fire did start. Additionally, using 6-sided metal cabinets or shelving with closeable doors will further reduce the calculated combustible loading.

DBF 1 involved a fuel leak from a truck brought into an unusual area near the north side of the west high bay. The probability of structural damage from a fire resulting from this fuel fire can be further reduced through administrative controls that include the following:

1) Stage a 100 lb CO_2 fire extinguisher with a long ejector hose near parked trucks that can reach into the engine compartment in the event of a motor fire.
2) Use mobile catch-basins under the vehicle when parked to capture any leaking fuel so that some or all the fuel can be contained prior to spreading to a large area.
3) Enforce combustible storage offsets from the vehicle so fire cannot easily spread to crating.
4) Use a flame inhibitor on crates to lower the potential HRR.
5) Keep combustible storage in islands, providing separation from other storage islands to help minimize the potential for fire spread.
6) Minimize overall combustible loading by utilizing other non-critical buildings for storage of combustibles.

During renovations, consider applying a fire rated material on the structural members. This section demonstrated that even without suppression, the structure will not experience degradation resulting in collapse or excessive deflection through burnout of all the applicable combustible materials if the structural members were protected with 2-hour insulative material. The best solution to preserving the structure is to provide structural fire protection. Intumescent paints are available that can be applied via a sprayer and are designed to have ratings corresponding to the ASTM E119 previously discussed. This type of intumescent paint would be ideal for office rooms that could be subject to flashover compartment fire conditions and to columns and beams that could be exposed to pool fires.

Intumescent paint provides a much more attractive and convenient solution than typical sprayed-on fire barrier materials.

Compartmentation is also highly recommended. As discussed in this report, this building has limited fire rated barriers. A reasonable step to improve structural survivability would be to include construction with specific fire ratings for alterations involving any interior wall spaces. In the event of seismic or other extreme events, where water delivery is affected by damaged piping or where the destruction of power supply systems is likely, this building has a reasonable probability of partial collapse if a fire occurred.

The low risk of having a fire where both suppression and firefighting personnel are unavailable justifies taking no immediate actions associated with structural upgrades, which is why the recommendation is made above to wait and include adding fire protection material to structural members during renovations. Cost benefits can be readily observed by transitioning office space storage from being in open shelving to utilizing 6-sided metal cabinets. This process is inexpensive and provides excellent protection against the spread of fire. Given the overall cost for such cabinets and the simplicity for installation, there is a significant cost advantage for this in the short-term. These added file and storage cabinets will assist in office and industrial areas to be better organized and enable operations to be more efficient. Additionally, following the recommendation to utilize flame retardant paint, such as Flamestop, will significantly reduce the potential for a traveling fire to damage structural members. The application of this fire-retardant stain to the exterior of wooden storage crates can be included in the shipping and receiving process.

PRESCRIPTIVE EVALUATION OF THE MOE

General Condition of the MOE

Figure 97 and Figure 98 show the 1st and 2nd floor layouts of this building with the exit doors and entrances to the exit access stairways highlighted in yellow. The fire rated barriers are shown with the red lines in these figures. Figure 84 also shows the fire rated barriers for the first floor. The doorways within these barriers are highlighted as horizontal exits. Horizontal exits require a two-hour fire rated separation according to Section 1026 of Reference (b). Most of these barriers were constructed in 1959 and their internal composition is unknown; however, the opening protectives meet the requirements for a 2-hour barrier as shown in Section 716 of Reference (b). The fire barriers are composed of Concrete Masonry Units and are assumed to be filled as some of them are load bearing as shown in Figure 84. It is assumed these barriers meet the requirements of a horizontal exit. The exit access travel distances evaluated in subsequent sections are calculated to either exterior doors or horizontal exits. The general conditions of the MOE components are compliant and acceptable.

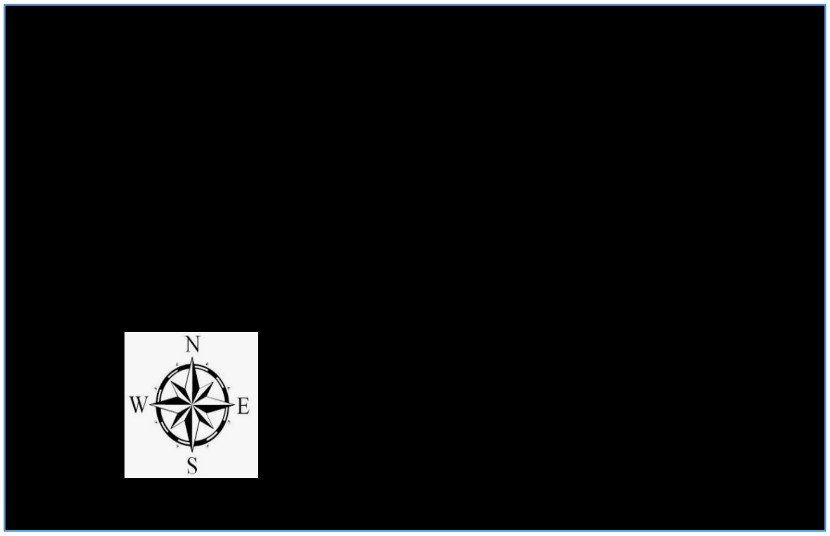


Figure 97: 1st floor of the ACME showing applicable exit doors and fire barriers.

[redacted]

Figure 98: 2nd floor of the ACME showing applicable exit doors and fire barriers.

Characterization of the Prescriptive MOE

The Design Occupant Load is calculated by relying on Table 1004.1.2 of the 2015 IBC, Reference (c), using the estimated Occupant Load Factors (OLF) as applicable for a given use. The 2015 OLFs are used for conservatism instead of the 2018 OLFs as this table changed in the 2018 version by increasing the minimum area allowances per person. The OLFs and respective occupancy uses are shown in Table 6. The OLFs are applied to the areas as shown in Table 7 and Table 8 to calculate the Design Occupant Load (OL). The areas that are within these two tables are derived from the layout drawings of the ACME Building that show each area as a function of actual use. The balloons which are shown in the figures between Figure 65 through Figure 81 inclusive are referenced in the first column in Table 7 and Table 8. The OL estimated through Table 6 is a minimum that is required to be used in calculating MOE components to ensure occupants can safely egress in an emergency. The Design OL is used only for the purpose of estimating a building's MOE capacity and does not act as a bounding value. A higher OL can be used in the applicable areas provided that the MOE has the capacity to support it, provided that the Fire Code Official (FCO) authorizes the increase.

Table 6: OLFs as shown in Table 1004.1.2 in the Reference (c).

MAXIMUM FLOOR AREA ALLOWANCES PER OCCUPANT

FUNCTION OF SPACE	OCCUPANT LOAD FACTOR[a]
Accessory storage areas, mechanical equipment room	300 gross
Agricultural building	300 gross
Aircraft hangars	500 gross
Airport terminal Baggage claim Baggage handling Concourse Waiting areas	 20 gross 300 gross 100 gross 15 gross
Assembly Gaming floors (keno, slots, etc.) Exhibit gallery and museum	 11 gross 30 net
Assembly with fixed seats	See Section 1004.4
Assembly without fixed seats Concentrated (chairs only – not fixed) Standing space Unconcentrated (tables and chairs)	 7 net 5 net 15 net
Bowling centers, allow 5 persons for each lane including 15 feet of runway, and for additional areas	7 net
Business areas	100 gross
Courtrooms – other than fixed seating areas	40 net
Day care	35 net
Dormitories	50 gross
Educational Classroom area Shops and other vocational room areas	 20 net 50 net
Exercise rooms	50 gross
Group H-5 Fabrication and manufacturing areas	200 gross
Industrial areas	100 gross
Institutional areas Inpatient treatment areas Outpatient areas Sleeping areas	 240 gross 100 gross 120 gross
Kitchens, commercial	200 gross
Library Reading rooms Stack area	 50 net 100 gross
Locker rooms	50 gross
Mall buildings – covered and open	See Section 402.8.2 of the *International Building Code*
Mercantile Storage, stock, shipping areas	60 gross 300 gross
Parking garages	200 gross
Residential	200 gross
Skating rinks, swimming pools Rink and pool Decks	 50 gross 15 gross
Stages and platforms	15 net
Warehouses	500 gross

Table 7: the ACME Building Complex First Floor Estimates for Design Occupant Load

The ACME Building Complex First Floor Use and Occupant Load					
Balloon	Area (ft^2)	Area Use	OLF (ft^2/person)	Occupant Load	Notes
1	2,313	Storage Space	300	8	West high-bay storage
2	12,079	Industrial Space	100	121	West high-bay operations
3	1,967	Storage Space	300	7	West high-bay storage
4	5,447	Industrial Space	100	55	Tool-room operations
5	10,675	Storage Space	300	36	Tool-room storage
6	2,543	Storage Space	300	9	West high-bay storage
7	5,004	Machine shop	100	51	Machine shop
8	280	Remote Access	0	0	No Occupancy
9	747	Storage Space	300	3	Machine shop storage
10	296	Storage Space	300	1	Slave repair storage
11	3,556	Industrial Space	100	36	Slave repair area
12	80	Stairway	100	1	Stairway to fan room
13	3,366	Unused Space	0	0	No Occupancy. Old chemistry wing.
14	752	Corridor	100	8	
15	119	Corridor	100	2	Access between HCOG and HCLA
16	180	Stairway	100	2	Stairway to fan room
17	316	Bathroom	100	4	
18	3,677	Locker Room	20	184	
19	155	Stairway	100	2	Covered exterior stairway
20	654	Showers	50	14	
21	204	Bathroom	100	3	
22	2,846	Remote Access	0	0	No Occupancy
23	660	Unused Space	0	0	No Occupancy. Blocked off due to security concerns.
24	4,678	Industrial Space	100	47	HCOG
25	120	Business	100	2	HCOG supervisor
26	761	Corridor	100	8	Access to turnstiles
27	521	Industrial Space	100	6	Electrical repair shop
28	5,492	Industrial Space	100	55	Repair area
29	69	Corridor	100	1	Vestibule
30	122	Stairway	100	2	Covered exterior stairway
31	168	Storage Space	300	1	FACP location
32	429	Showers	50	9	
33	108	Bathroom	100	2	
34	216	Bathroom	100	3	
35	145	Stairway	100	2	Interior exit access stairway
36	62	Storage Space	300	1	Janitors' closet

The ACME Building Complex First Floor Use and Occupant Load					
Balloon	Area (ft^2)	Area Use	OLF (ft^2/person)	Occupant Load	Notes
37	85	Industrial Space	100	1	Observation deck access
38	1,652	Office Space	100	17	
39	652	Storage Space	300	3	
40	1,797	Eating Rooms	15	120	1st floor lunchroom and vending services
41	170	Storage Space	300	1	
42	991	Corridor	100	10	Main corridor
43	497	Conference room	20	25	POD
44	118	Stairway	100	2	Interior exit access stairway
45	814	Office Space	100	9	
46	231	Storage Space	300	1	
47	207	Utility Space	300	1	
48	5,372	Aisle and Industrial	100	54	North beach that is composed of main aisleway and industrial equipment
49	7,507	Industrial Space	100	76	Water-pool industrial area
50	9,801	Remote Access	0	0	No Occupancy
51	2,854	Office Space	100	29	
52	9,494	Industrial Space	100	95	Defueling and Maintenance Stand (DMS) Area
53	317	Corridor	100	4	
54	210	Storage Space	300	1	
55	116	Bathroom	100	2	
56	99	Storage Space	300	1	
57	81	Stairway	100	1	Exterior exit access stairway
58	176	Office Space	100	2	
59	176	Storage Space	300	1	
60	88	Stairway	100	1	Interior exit access stairway for DMS equipment storage
61	1,243	Industrial Space	100	13	Sailmaker shop
62	597	Storage Space	300	2	
63	2,212	Storage Space	300	8	General east high-bay storage
64	593	Storage Space	300	2	
65	10,618	Industrial Space	100	107	SFPF-North
66	493	Storage Space	300	2	
67	92	Stairway	100	1	Equipment room exit access stairway
68	99	Stairway	100	1	DMS mezzanine stairway
69	199	Stairway	100	2	DMS mezzanine stairway

The ACME Building Complex First Floor Use and Occupant Load					
Balloon	Area (ft^2)	Area Use	OLF (ft^2/person)	Occupant Load	Notes
70	1,304	Aisle and Industrial	100	14	SFPF-N support staff area
71	1,437	Industrial Office Support	100	15	
72	238	Corridor	100	3	
73	362	Bathroom	100	4	
74	687	Office Space	100	7	
75	318	Utility Space	300	2	
76	97	Corridor	100	1	
77	1,264	Eating Rooms	15	85	SFPF Breakroom
78	833	Corridor	100	9	
79	608	Storage Space	300	3	
80	19,634	Industrial Space	100	197	SFPF industrial area
81	2,227	Storage Space	300	8	SFPF south storage area
82	163	Stairway	100	2	SFPF utility room exit access stairway
83	1,206	Storage Space	300	5	
84	6,798	Industrial Space	100	68	Waste processing area
85	607	Storage Space	300	3	
86	200	Containers	0	0	No Occupancy. Containers staged to transport waste.
87	200	Containers	0	0	No Occupancy. Containers staged to transport waste.
88	472	Storage Space	300	2	
89	6,511	Aisle and Industrial	100	66	South beach area
90	866	Utility Space	300	3	
91	866	Utility Space	300	3	
92	93	Unused Space	0	0	No Occupancy
93	265	Office Space	100	3	
94	83	Storage Space	300	1	
95	890	Office Space	100	9	
96	1,597	Unused Space	0	0	No Occupancy
97	1,133	Utility Space	300	4	
98	1,343	Unoccupied	0	0	No Occupancy. Tunnel access area.
99	12,007	Industrial Space	100	121	MERS area
100	760	Unoccupied	0	0	No Occupancy
101	707	Remote Access	0	0	No Occupancy
102	594	Utility Space	300	2	
103	461	Office Space	100	5	
104	567	Office Space	100	6	

Table 8: the ACME Building Complex 2nd Floor Estimates for Design Occupant Load.

the ACME Building Complex Second Floor Use and Occupant Load					
Balloon	Area (ft^2)	Area Use	OLF (ft^2/person)	Occupant Load	Notes
105	N/A	High-Bay	N/A	N/A	No Occupancy on 2nd Floor
106	N/A	Stairway	N/A	N/A	Corresponds to Balloon #12
107	9,217	Utility Space	300	31	Utility areas OL will apply to first floor
108	1,384	Unused Space	0	0	No Occupancy
109	N/A	Stairway	N/A	N/A	Corresponds to Balloon #17
110	N/A	Stairway	N/A	N/A	Corresponds to Balloon #19
111	399	Aisle	100	4	
112	1,857	Office Space	100	19	
113	1,496	Equipment Access	300	5	Utility areas OL will apply to 1st floor for egress
114	N/A	Stairway	N/A	N/A	Corresponds to Balloon #30
115	1,313	Corridor	100	14	
116	244	Bathroom	100	3	
117	128	Utility Space	300	1	
118	220	Bathroom	100	3	
119	2,161	Office Space	100	22	
120	N/A	Stairway	100	0	Corresponds to Balloon #35
121	570	Eating Rooms	15	38	
122	1,304	Conference room	20	66	
123	146	Conference room	20	8	
124	N/A	Corridor	N/A	N/A	Corresponds to Balloon #115
125	N/A	Stairway	N/A	N/A	Corresponds to Balloon #44
126	4,068	Office Space	100	41	
127	80	Corridor	100	1	
128	115	Stairway	100	2	
129	245	Corridor	100	3	
130	N/A	Stairway	N/A	N/A	Corresponds to Balloon #57
131	115	Utility Space	300	1	
132	39	Storage Space	300	1	
133	89	Bathroom	100	1	
134	N/A	Stairway	N/A	N/A	Corresponds to Balloon #68
135	318	Remote Access	0	0	No Occupancy
136	1,597	Industrial Space	100	16	DMS Area OL will apply to 1st floor egress
137	1,148	Storage Space	300	4	
138	N/A	Stairway	N/A	N/A	Corresponds to Balloon #60
139	544	Storage Space	300	2	DMS Area OL will apply to 1st floor egress
140	N/A	Stairway	N/A	N/A	Corresponds to Balloon #67
141	1,243	Utility Space	300	5	Electrical Equipment Mezzanine OL will apply to first floor

the ACME Building Complex Second Floor Use and Occupant Load					
Balloon	Area (ft^2)	Area Use	OLF (ft^2/person)	Occupant Load	Notes
142	124	Stairway	100	2	
143	N/A	Stairway	N/A	N/A	Corresponds to Balloon #69
144	6,053	Utility Space	300	21	
145	N/A	Stairway	N/A	N/A	Corresponds to Balloon #82

The OL for the first floor includes the OL equipment mezzanines (Balloons 102, 113, 136, 137, 139, 141, and 144). This combined OL is used as these second-floor locations egress down into the first floor MOE, combining with the occupants egressing from the first-floor industrial areas. This combined occupant load is shown in Table 9. The second-floor office area is on the north side of the building. The area and OL for the second-floor areas is in Table 10.

Table 9: Occupant Load that applies to the 1st floor MOE.

Occupancy Load for the MOE of the First Floor of the ACME Building	
Applicable Area	211,953 ft^2
OL	1881 people

Table 10: Occupant Load that applies to the second floor MOE of the ACME Building.

Occupancy Load for the MOE of the Second Floor of the ACME Building:	
Area	13,093 ft^2
Occupant Load	228 People

Doors, Corridors and Stairs
All exit doors from the ACME Building provide at least 32" of clear width. There are 27 exit doors around the perimeter of the first floor of this building complex. Within the building, any exit access doorways that are adjacent to aisles and corridors are represented as corridors or aisles within Table 11 where the occupant load that can be supported is calculated. Stairway widths and occupant capacities are also shown within this table. All corridors, aisles, stairways, and doors have been inspected and found to be compliant with the code of records for when the building phases were completed, or to have active work tasks to correct deficiencies.

the ACME Building has an NFPA 13 compliant sprinkler system within it. Exception 1 of Section 1005.3.1 of Reference (b) specifies that the MOE Capacity Factor (CF) for sizing the OL for a stairway is 0.2" per person. The CF for doors is 0.15" per person per Exception 1 of Section 1005.3.2. Table 11 uses these CF values in calculating the OL for each corridor, aisle, and stairway.

The overall OL that can be supported by the exterior doors of the first floor of the ACME Building acts as a maximum permissible OL for the first floor of the building. That value is calculated as follows:

MOE OL = Number of exterior doors * Door clear width / CF

Number of exterior doors = 27

Door clear width = 32"

CF = 0.15"/person for non-stairway components

MOE OL = 27 doors * 32”per door / 0.15”per person
MOE OL = 5,800 people

As shown in Table 9, the design OL for the first floor of the ACME Building is 1,881 people. The exterior doors provide capacity for 5,800 people, showing that the MOE door sizing of the first floor is adequate.

NOTE: The Fire code official that manages the fire protection policies for the ACME Building has authorized several of the doors to be sealed so these doors do not need to be inspected by security. This permission does not affect the necessary MOE for the occupancy load of the building because of the redundant exit doors as demonstrated by the above calculation. This permission does not affect the subsequent distance calculations.

The widths of the respective corridors are specified in Table 11 based upon the smallest clear width associated with the access to the corridor, rather than the corridor width. Typical corridor widths within the ACME Building are 60” wide; however, the doors accessing the corridors limit that width down to the doorway’s clear width of 32”. 35” wide corridors are used in estimating the performance-based egress time later in this report and provide a conservative boundary for this analysis.

Table 11: Corridors, Aisles and Stairways that are a part of the Means of Egress.

Means of Egress Components					
Balloon	Component	Width (in)	CF (inch/person)	OL (people)	Notes
12	Stairway	36	0.2	180	West fan room stairway
14	Corridor	35	0.15	233	Corridor serving unoccupied chemistry wing (door limiting)
15	Corridor	35	0.15	233	Small corridor connecting HCOG to HCLA (door limiting)
16	Stairway	24	0.2	120	East fan room stairway
19	Stairway	44	0.2	220	North techs area stairway
26	Corridor	35	0.15	233	Corridor leading into HCOG (door limiting)
29	Corridor	35	0.15	233	Vestibule (door limiting)
30	Stairway	44	0.2	220	North SRE stairway
35	Stairway	44	0.2	220	Center northeast SRE stairway
42	Corridor	35	0.15	233	Main northeast corridor (door limiting)
44	Stairway	44	0.2	220	East stairway
48	Aisle	36	0.15	240	North Beach Aisle Space
53	Corridor	35	0.15	233	Northeast entrance (door limiting)
57	Stairway	44	0.2	220	Northeast SRE stairway
60	Stairway	36	0.2	180	DMS Storage Mezzanine
67	Stairway	36	0.2	180	DMS west stairway
68	Stairway	36	0.2	180	DMS east stairway
69	Stairway	44	0.2	220	SFPF-N equipment stairway
70	Aisle	35	0.15	233	SFPF access (door limiting)
72	Corridor	35	0.15	233	SFPF access (door limiting)
76	Corridor	35	0.15	233	SFPF personnel (door limiting)
78	Corridor	35	0.15	233	SFPF personnel (door limiting)

Means of Egress Components					
Balloon	Component	Width (in)	CF (inch/person)	OL (people)	Notes
82	Stairway	44	0.2	220	SFPF equipment (door limited)
89	Aisle	36	0.15	240	South beach aisle and equipment space
111	Aisle	35	0.15	233	Tech area (door limited)
114	Stairway	44	0.2	220	North stairway
115	Corridor	35	0.15	233	Main 2nd floor corridor (door limited)
125	Stairway	44	0.2	220	East interior exit access stairway
127	Corridor	35	0.15	233	2nd floor corridor (door limited)
128	Stairway	44	0.2	220	East interior exit access stairway
129	Corridor	35	0.15	233	East corridor (door limited)
130	Stairway	44	0.2	220	East exterior exit access stairway
138	Stairway	36	0.2	180	DMS Storage interior exit access stairway
142	Stairway	36	0.2	180	Equipment mezzanine access

There are three exterior exit access stairways and three interior exit access stairways that provide egress for the 2nd floor office areas. All six of the stairways are approximately 44" and are the limiting factor for egress time as they restrict the occupancy flow more than the clear width of the doors which is conservatively measured at 32" but is wider in most cases. The capacity of the 2nd floor MOE is:

6 * 44" / 0.2" per person = 1,320 people.

As specified in Table 10, the OL for the second-floor office area is 228 people. The MOE has adequate capacity.

The 2nd floor office area maximum diagonal distance is 340'. The 1st floor maximum diagonal distance is 981'. Reference (b) Section 1007.1.1: Exception 2 specifies that the minimum exit separation between the most extreme exits shall be $\geq$1/3 of the maximum diagonal dimension. By inspection, the exit doors are appropriately spaced to meet this requirement. By inspection adequate spacing is provided for the exit access doors for the fan-room (Balloon #107) and for the South Bay utility room (Balloon #144). Both second-floor utility spaces are longer than 75' and are required to have two appropriately spaced exit access doors according to Table 1006.2.1 in Reference (b) as shown in Table 12, for Group U accessory occupancies. Both the number of exit access doors and the placement is met in the existing design. The second-floor conference room (Balloon 122) has an OL of 66 people. Table 1006.2.1 of Reference (b) requires two doors for Group A rooms in this building. Two doors are provided for this conference room and are appropriately spaced. The first-floor lunch and break room (Balloon 40) has an OL of 120 people. This Group A-2 accessory space requires two exit access doors. This space has four exit access doors, so meets this requirement, but the doors open inward against the flow of occupants which is a violation against Section 1010.1.2.1 of Reference (b). Furthermore, there is an adjacent office area that uses this lunchroom as an egress route resulting in a posted maximum occupancy of 42 people in this lunchroom area so that code compliance is maintained. Removing the egress doors is recommended to eliminate this problem, as these doors are not fire rated and are frequently propped open. An inspection of all other rooms within this building has found no deficiencies with the number of exits or the exit door placement.

Section 1010.1.2.1 of Reference (b) specifies that the direction of door swing shall be in the direction of egress travel for areas that have more than 49 people. There is one corridor location that violates this requirement, and that location has a task scheduled to correct this problem.

Table 12: Table 1006.2.1 from Reference (b) showing common path of travel distances and number of exit requirements.

[BE] TABLE 1006.2.1
SPACES WITH ONE EXIT OR EXIT ACCESS DOORWAY

OCCUPANCY	MAXIMUM OCCUPANT LOAD OF SPACE	MAXIMUM COMMON PATH OF EGRESS TRAVEL DISTANCE (feet)		
		Without Sprinkler System (feet)		With Sprinkler System (feet)
		Occupant Load		
		OL ≤ 30	OL > 30	
A[c], E, M	49	75	75	75[a]
B	49	100	75	100[a]
F	49	75	75	100[a]
H-1, H-2, H-3	3	NP	NP	25[b]
H-4, H-5	10	NP	NP	75[b]
I-1, I-2[d], I-4	10	NP	NP	75[a]
I-3	10	NP	NP	100[a]
R-1	10	NP	NP	75[a]
R-2	10	NP	NP	125[a]
R-3[e]	10	NP	NP	125[a]
R-4[e]	10	75	75	125[a]
S[f]	29	100	75	100[a]
U	49	100	75	75[a]

The assembly use areas discussed above, which are defined as those conference and lunchrooms with an OL above 49 people, are required to have a posted sign showing the allowable OL within those respective areas per Section 1004.9 of Reference (b). The locations meeting this assembly use occupancy size have been inspected and have been verified as having the required postings. It was also observed that rooms under the 50 person OL also have postings limiting their occupancy number. Signs in these smaller rooms are not required by code and these occupancy limits likely overly restrict the use of these locations. Small rooms used for business occupancies do not have the egress challenges that assembly locations have. Their means of egress component sizing, even at minimum door sizes, is sufficient for far more people than can comfortably fit within these locations.

Exit Sign Compliance

Section 1013.1 of Reference (b) requires readily visible exit signs for rooms or areas that require more than one door. These exit signs are required to be visible within 100 ft from any point within a corridor. The exit signs were inspected throughout this building and found to be compliant with these code requirements. Figure 99 is included below and shows a portion of the 2nd floor business occupancy with the exit signs circled. This is a representative example of the remainder of the building.

Figure 99: Exit sign placement for a portion of the 2nd floor office area.

Travel Distance

The maximum allowable exit access travel distance in the high-bay locations is 400' per Section 1017.2.2 of Reference (b). Allowable travel distances for the balance of the building are 300' for the office areas, and 250' for the remainder of the building. The number of exits, arrangement of exits, exit widths, common-path-of-travel requirements, dead-end requirements, and other requirements for emergency egress not discussed above are compliant and provide adequate exit access for occupants to safely egress in emergency situations.

Catwalks for processing areas and for crane operator compartment access shall be considered as equipment access platforms and shall be required to meet Occupational Safety and Health Act (OSHA) requirements rather than the MOE requirements found in Chapter 10 of Reference (b). Emergency egress from these locations is addressed through a combination of procedures and training. The 400' exit access travel distance limit is violated at locations on the catwalks. Subsequent sections of this analysis will show that there is ample time to egress due to the capacity of the high bay to absorb smoke because of its high ceilings.

PERFORMANCE BASED REVIEW OF MOE

Characteristics of Occupants

The occupants of the ACME Building are trained personnel that are familiar with the building. The ability to perform industrial work is a prerequisite for working within this facility. This building has a fully compliant NFPA 72 manual fire protection system and an Emergency Voice Alarm Communication System, and the personnel are drilled on their fire evacuation response at least annually. In addition to the fire evacuation drills outlined within Section 405 of Reference (a) that are performed annually, added drills are also performed each year regarding emergency alarms associated with process related hazards. Because of these factors, there is a high degree of occupant readiness to respond to an emergency.

Pre-Movement Activities and Times

Required Safe Egress Time (RSET) is the sum of different portions of time associated with egress with a safety factor (SF) of 1.5 applied to the calculated evacuation time (t_{trav}). The following model summarizes the components of RSET:

$$RSET = t_{det} + t_{warn} + t_{pre} + SF*t_{trav} \qquad \textbf{\textit{(Equation 1)}}$$

t_{det} = Time from fire ignition to detection
t_{warn} = Time from detection to notification of occupants of fire emergency
t_{pre} = Time from notification until evacuation commences
t_{trav} = Time from start of evacuation movement until safety is reached

This model is graphically shown in Figure 100 below.

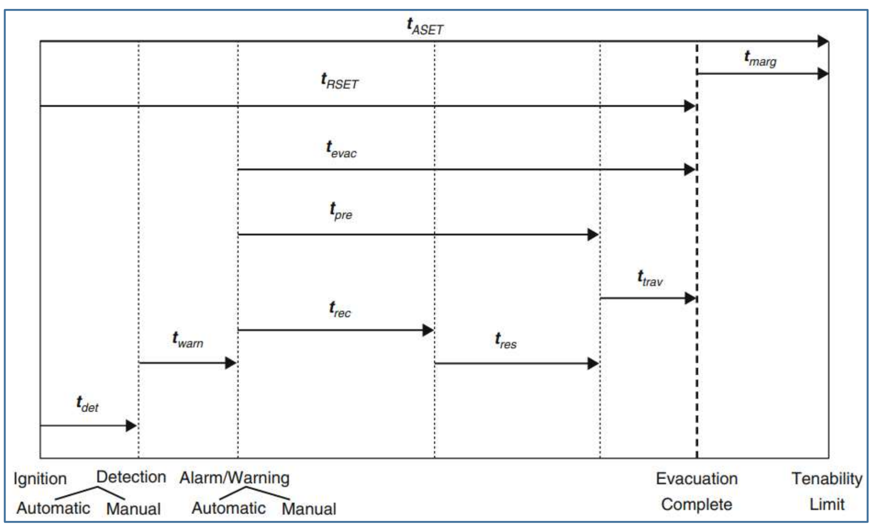


Figure 100: Factors in Evaluating Egress Time (Table 64.2 from Reference (h)).

Fire Evacuation Drills for the ACME Building are observed by several drill control personnel to ensure performance is prompt. Any delays in properly egressing during these drills result in remedial training for personnel that violated the evacuation policies. This feedback loop ensures personnel are appropriately conditioned on the importance of fast evacuation in the event of an emergency. Typical egress times for drills are approximately two to three minutes to empty the entire building from the time the annunciating devices are triggered.

Figure 101 shows delay times derived from actual fires and evacuation exercises as reported within Reference (k). The ACME Building is a mixed-use occupancy; however, its second floor is used for business type work. The highlighted section in Figure 101 for the "mid-rise office building" is a suitable bounding upper limit for potential pre-movement time (t_{pre}) for the general population that is awake and performing office work. That "<4" minute time with a mean of 0.6 minute provides an upper boundary for the typical population that does not undergo rigorous training and drilling on evacuation. When considering that the staff that occupies the ACME Building is well trained and drilled, and when observing the performance of the emergency evacuation drills that show total egress times typically at about two minutes that includes both pre-movement time and evacuation time, it is safe to specify a one-minute pre-movement time as an upper limit. Local policies that personnel are trained and drilled on specify immediate action when emergency notifications are sounded. Only minimal detours that do not impact overall egress time are permitted. Based upon these policies, training, and drilling, the t_{pre} is assigned the value of one minute.

t_{pre} = *1 minute*

Event Description	*N*	*Min*	*1st Q*	*Median*	*3rd Q*	*Max*	*Mean*	*Factors*
High-rise hotel[14]	536	0	3.3	60.0	130.9	290.0	NA*	MGM Grand Hotel fire, no alarm notification, grouped data from questionnaires
High-rise hotel[15]	47	0	2.0	5.0	17.5	120.0	NA	Westchase Hilton Hotel fire, no alarm in early stages, grouped data from questionnaires
High-rise office building[16]	85	0	2.0	5.0	10.0	245.0	11.3	World Trade Center explosion and fire, no alarm notification (building closer to explosion)
High-rise office building[16]	46	0	4.5	10.0	31.5	185.0	28.4	World Trade Center explosion and fire, no alarm notification (building further from blast)
High-rise office building[17]	107	1.0	1.0	1.0	1.0	~6.0	NA	Fire incident, no alarms, data from interviews with occupants of four floors of building (11 interviewees were trapped)
High-rise office building[18]	12	0.5	NA	1.0	NA	2.3	1.2	Unannounced drill on three floors; data for first person to reach each of four stairwell doors to wait for voice instruction; trained staff; data from video recordings
Mid-rise office building[19]	92	0	0.4	0.6	0.8	<4.0	0.6	Unannounced drill, good alarm performance; fire wardens; warm day
Mid-rise office building[19]	161	0	0.5	0.9	1.4	<5.0	1.1	Unannounced drill, good alarm performance; fire wardens; cool day
One-story department store[20,21]	95	1.0	0.2	0.3	0.5	0.9	0.4	Unannounced drill; trained staff; data here derived from grouped data for 95 participants
Three-story department store[21]	122	0.05	NA	NA	NA	1.6	0.6	Unannounced drill; trained staff; times distilled from analysis of videotapes

Figure 101: Delay time data derived from actual fires and evacuation exercise as published in Table 4.2.1 of Reference (k).

Emergency movement Components of Evacuation Time

This section calculates the RSET using the Hydraulic model from Chapter 59 of Reference (h).

Assumptions:

The following assumptions and bounding conditions are employed in the model of human flow calculations to assess human behavior during emergency movement:

- These calculations evaluate the likely exit access paths of the remote egress routes originating on floors and mezzanines where personnel may be working. This assumption results in exit access distances that exceed the code allowable distances. This is realistic in an emergency situation as personnel will likely take the path they are familiar with instead of the shortest routes.
- All occupants start evacuating at the same time.
- Evacuees are free of impairments/disabilities that impede their movement.
- Evacuee mobility characteristics are assumed to be uniform across the population.
- The detection time is assumed to be 75 seconds. This assumption is based upon personnel recognizing a smoke smell, initiating emergency actions, and activating a manual pull station (t_{det} = 1.25 minutes). Table 85.9 of Reference (h) shows a typical detection time of 135 seconds; however, the 75 second detection time used in this analysis reflects the results of fire simulations in drills within the ACME Building. Personnel have been trained to respond quickly to signs of fire or smoke and drills have validated that 75 seconds is a reasonable value.
- To address any potential modeling errors in the Reference (h) Chapter 59 human flow equations, a 50% Safety Factor (SF) will be added to the estimated travel time.
- Tenability criteria is based on a minimal exposure approach of combustion gases to building occupants based upon Method 2 as defined in Section A5.2.2 of the 2018 Life Safety Code, Reference (m). This will be discussed in subsequent sections.
- Safe egress from the fire is assumed to be achieved if the RSET is shorter than the Available Safe Egress Time (ASET).
- For analytical convenience, all exit and exit access doors will be modeled at 32” clear width.
- Stair risers and treads throughout the area are conservatively represented by a 7.5/10 stair design (7.5” riser and 10” tread). The stairways typically have a more appropriate 7/11 design but using the 7.5/10 design is conservative and makes up for potential measurement errors.
- All occupants within a “calculation zone” shall be assembled when the fire situation is recognized. This is intended to represent personnel huddled together for a pre-job briefing or performing an equipment inspection. They will have an initial density of 0.1 persons/ft^2. This is a conservative assumption as it creates a queueing effect that will delay egress.
- The stairway widths shown in Table 11 show both 36” and 44” stairways. A 36” stairway will be used throughout this analysis to maintain conservatism and make up for any weaknesses in field measurements.
- Applying Reference (h) Table 59.1, the applicable stairway widths provide the following clear widths for stairways (W_{es}) that will be used in calculating applicable flow:

  36” – 2*6” = **24”**
- Corridors and aisles will be modeled as 36” wide. Table 11 shows corridor and aisles to be under this value, but that was based upon the doors that limited access to these MOE components. Using 36” will conservatively capture all the corridors and aisles that will be examined in this section and avoid errors, as most corridors and aisles are 60” wide. Applying Reference (h) Table 59.1, the applicable width is 36” – 2*8” = 20” (1.67 ft) for egress calculation width (W_{ea}).
- By modeling doors as having a minimum clear width of 32”, per Table 59.1 of Reference (h) 5th edition, the egress calculation width (W_{ed}) is 20” (1.67 ft), which is the same as the corridor and aisle

width. This enables the same calculated flow (F_c) to be applied to doors as corridors and aisles. Most doors shall be larger than this value, so this is a conservative estimate.

- The time to open a door is negligible as applied to the whole population egressing sequentially through a door after it has been opened.

METHODOLOGY

This calculation will evaluate the three egress paths identified in the figures below: Egress Path #1, Egress Path #2, and Egress Path #3. These paths were chosen to represent the worst-case locations for an immediate egress.

CALCULATING RSET

The value for Equation 1 was developed from Equation 59.1 in the Reference (h) and will be used for establishing RSET. The variables t_{det}, t_{warn}, and t_{pre} from Equation 1 can be combined into a single estimate for time. The warning time (t_{warn}) includes time for personnel aware of the fire situation to directly warn others, but also any time lags associated with annunciation devices activating. As stated in the assumptions, t_{det} includes the time for personnel to activate a manual alarm. Personnel are routinely trained and drilled on the importance of warning others while evacuating so verbal cues will be active during the evacuation process. A total of 30 seconds is assigned for the time for warning other personnel.

$t_{warn} = 0.5$ *minute*

The combination of t_{det}, t_{warn}, and t_{pre} gives the value as follows:

$t_{det} + t_{warn} + t_{pre} = 2.75$ *minutes*

The remaining variable from Equation 1 for evaluating RSET is the evacuation travel time (t_{trav}). This value will follow the formulas within Chapter 59 of the Reference (h). The following variables will be used for this calculation:

Variables

$a = 2.86$	*Constant from Reference (h) Table 59.2*
$D = 0.1$ persons/ft^2	*See Assumptions*
F_c = Calculated flow (persons/minute)	
F_s = Specific flow (persons/minute/ft)	*Reference (h) Table 59.5*
k = Constant (275 for corridors; 196 for stairs)	*Reference (h) Table 59.2*
L_c = Length of corridor or aisle (ft)	
L_{c1} = Length of corridor or aisle for egress path 1 (ft)	
L_{c2} = Length of corridor or aisle for egress path 2 (ft)	
L_{c3} = Length of corridor or aisle for egress path 3 (ft)	
L_d = Generic term for distance	
L_1 = Total length of egress path 1	

L_2 = Total length of egress path 2
L_3 = Total length of egress path 3
N = Number of stairs
N_1 = Number of stairs in egress path #1
N_2 = Number of stairs in egress path #2
N_3 = Number of stairs in egress path #3
P = Population size (persons)
S = Speed along the line of travel (ft/minute)
SF = 1.5 *See Assumptions*
t_{det} = 1.25 minutes
t_{warn} = 1 minute
t_{pre} = 1 minute
t_{trav} = Time from start of evacuation movement until safety is reached
t_p = Time for passage of a queued group (minutes) into initial egress component
t_s = Time to cross means of egress components (minutes)
t_{sc} = Time to cross means of egress component for corridors and aisles (minutes)
t_{ssc} = Time to cross one-foot of corridor or aisle (minutes/ft)
t_{sss} = Time to cross single stair (minutes/stair)
t_{st} = Time to cross means of egress component for stairs (minutes)
W_e = Effective width (W_{es}, W_{ea} or W_{ed}) of stairway, aisle/corridor, and door components (ft)
X = Occupant load for remote area being analyzed

Formulas

$S = k - a * k * D$	*Equation 2; Reference (h) Eq. 59.5*
$F_s = (1-a * D)k * D$	*Equation 3; Reference (h) Eq. 59.7*
$F_c = Fs * We$	*Equation 4; Reference (h) Eq. 59.8*
$F_c = (1 - a * D)k * D * W_e$	*Equation 5; Reference (h) Eq. 59.9*
$t_p = P/[(1-a * D)k * D * W_e]$	*Equation 6; Reference (h) Eq. 59.11*
$t_p = P/F_c$	*Equation 7; Combining Eqs. 6, 5, 4 & 2*
$F_c = S * D * W_e$	*Equation 8; Combining Eqs. 2, 3 & 4*
$t_{st} = t_{sss} * N$	*Equation 9*
$t_{sc} = t_{ssc} * L_c$	*Equation 10*
$t_s = t_{st} + t_{sc}$	*Equation 11*
$t_{trav} = t_s + t_p$	*Equation 12*
$t_{trav} = t_{sss} * N + t_{ssc} * L_c + t_p$	*Equation 13*
$t_{det} + t_{warn} + t_{pre} = 2.75$ *minutes*	*See assumptions*
$RSET = t_{det} + t_{warn} + t_{pre} + SF*t_{trav}$	*Equation 14*
$RSET = 2.75 \text{ minutes} + SF*t_{trav}$	*Equation 15*

From Reference (h) Table 59.2:

k = 275 for corridors and aisles
k = 196 for stairs (7.5” risers and 10” treads)

Aisle and Corridor Means of Egress Calculations

Pedestrian egress speed for aisles and corridors:

$S = k – a * k * D$ *Equation 2*

$S = 275 – 2.86 * 275 * 0.1$ persons/ft^2 *Equation 2*

$S = 196$ ft/min

The time (t_{ssc}) to cross each-foot of corridor or aisle distance is:

t_{ssc} = Distance / Speed

$t_{ssc} = L_d / S$

t_{ssc} = (1 ft) / 196 ft/min

t_{ssc} = 0.0051 minute/ft *Equation 16 (time for each foot traveled)*

The value for t_{ssc} for corridors and aisles will be the same as the value for doors based upon the assumptions.

The time it takes for the last of “X” number of people to start down the corridor or aisle:

$F_c = S * D * W_{ea}$ *Equation 8*

W_{ea} = 1.67’ *See Assumptions*

F_c = 196 ft/min * 0.1 persons/ft^2 * 1.67 ft

F_c = 32.7 persons/min

t_p = X persons / 32.7 persons/min

t_p = 0.0306 * X min *Equation 17*

Stairway Means of Egress Calculations

The flow of persons into the corridor or aisle from their work area will be the same as the flow of persons into the stairway. The same flow of persons (F_c) used for the corridors/aisles will be used for the stairs:

F_c = 32.7 persons/min

$F_c = (1 – a * D) * k * D * W_{es}$ *Equation 5*

k = 196 for stairway

W_{es} = 2’ or 2.5’ *See Assumptions*

32.7 persons/min = $(1 – 2.86 * D) * 196 * D * W_{es}$

Using the quadratic equation and using the smaller of the two roots -> Solving for D:

D (36” stairway) = 0.14 people/ft^2

$S = k – a * k * D$ *Equation 2*

$S = 196 – 2.86 * 196 * 0.14$ persons/ft^2

S = 118 ft/min

With 1 riser and 1 tread, the diagonal length (L_d) for a 7.5/10 stair is:

$L_d = (10^2 + 7.5^2)^{1/2}$ in * 1 ft / 12 in *Pythagorean Theorem*

$L_d = 1.042$ ft

The time (t_s) to cross each stair is:

$t_{sss} = L_d / S$

$t_{sss} = 1.042 \text{ ft} / 118 \text{ ft/min}$

$t_{sss} = 0.0088$ minute/stair *Equation 18*

RSET Estimates for Egress Paths #1 through #3:

Egress Path #1

Figure 102 and Figure 103 show Egress Path #1. The starting point for Egress Path #1 is shown in Figure 55. This path egresses down the stairs (Balloon 11) into the first-floor industrial area (Balloon 12) and to the double doors entering the area defined by Balloon 14. These balloons are shown in Figure *68*. The double doors are a protective opening through a two-hour rated horizontal exit.

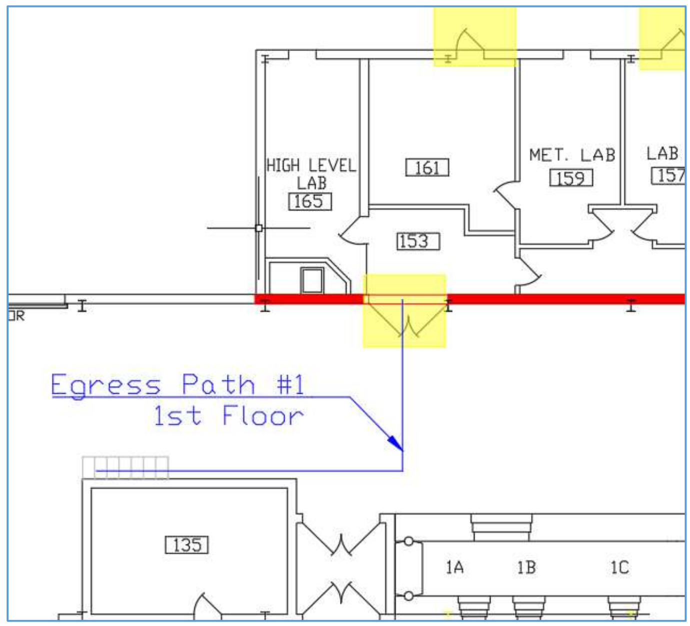


Figure 102: 1st floor section of Egress path #1.

This path has approximately 56 individual stairs and a horizontal travel distance of 270' over flat surfaces excluding the stairs. The 3rd floor mezzanine equipment platform is 35' above the first floor and is identified in Figure 103. It is not normally occupied; however, it is a utility occupancy with about 400 square feet. Per Table 6, this area would have a design occupancy of 2 people. For this analysis, this area is simulated as having 4 people that are performing an inspection of equipment at the time of the emergency.

It is assumed that the 2nd floor below this mezzanine is occupied based upon the OL as defined within Table 7. This small OL will have already started egressing before the 4 people on the equipment platform reach the second floor. The 2nd floor OL will not impact the egress time of these 4 people due to queuing.

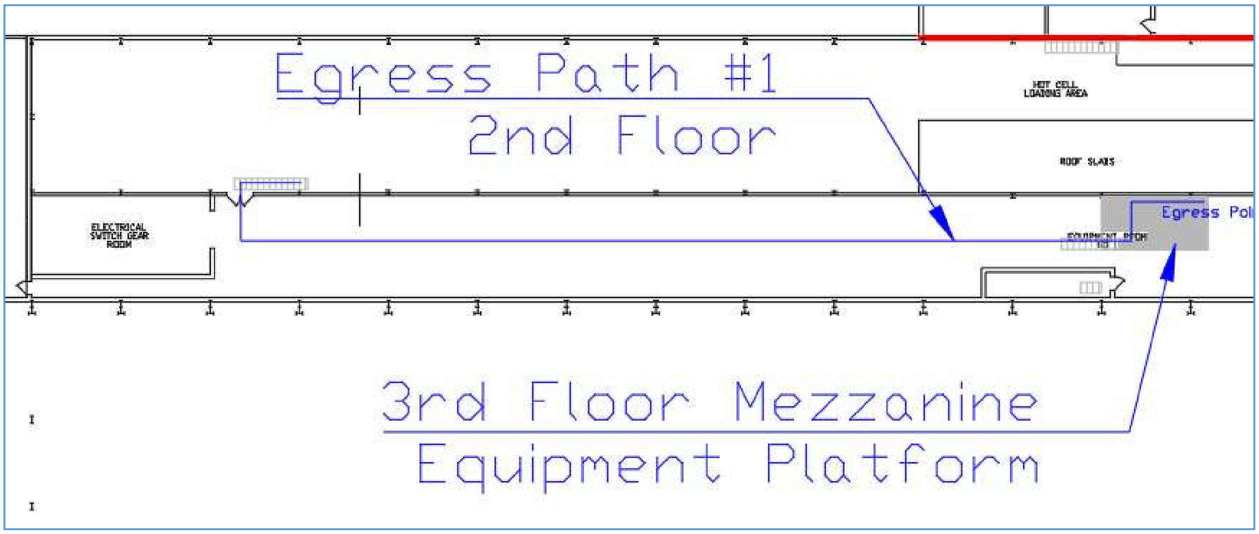


Figure 103: Egress path from equipment mezzanine above 2nd-floor equipment area (Balloon 107).

The time to travel (t_{trav}) Egress Path #1 is as follows:

$t_{trav} = t_s + t_p$ *Equation 12*

$t_s = t_{st} + t_{sc}$ *Equation 12*

$t_{st} = t_{sss} * N$ *Equation 9*

$t_{sss} = 0.0088$ minute/stair *Equation 18*

N = 56 stairs

$t_{st} = 0.0088$ minute/stair * 56 stairs

$t_{st} =0.5$ minute

$t_{sc} = t_{ssc} * L_c$ *Equation 10*

$t_{ssc} = 0.0051$ minute/ft *Equation 16*

$L_c = 270'$

$t_{sc} = 0.0051$ minute/ft * 270'

$t_{sc} = 1.4$ minutes

$t_s = 0.5$ minute + 1.4 minutes

$t_s = 1.9$ minutes.

$t_p = 0.0306 * X$ *Equation 16*

X = 4 people

$t_p =0.12$ minute

$t_{trav} = 1.9$ minutes + 0.12 minute

$t_{trav} = 2.02$ minutes for exit egress travel time

RSET = $t_{det} + t_{warn} + t_{pre} + SF*t_{trav}$ *Equation 1*

$t_{det} + t_{warn} + t_{pre} = 2.75$ minutes

SF = 1.5 *See assumptions*

*RSET = 2.75 minutes + 1.5 * 2.02 minutes

**This location is unique due to its location in a noisy fan-room. The small mezzanine location may be isolated from the warning shouts occurring from personnel responding due to a fire in the high bay. Personnel in this location will sense smoke through sight or smell coming through the fan room. This location has the benefit of quick access to a stairway from the mezzanine that lowers occupants below the smoke layer. The estimated pre-movement time from this location is likely much less than 2.75 minutes (Equation 1.4) making the actual RSET for this location less than what is shown. The time to reach the stairs from the worst location on this mezzanine is t_{ssc} = 0.0051 minute/ft * 20 ft = 6.1 seconds. Even with the 1.5 safety factor applied, the time to reach the stairs is 9.2 seconds. Personnel descending the stairs will descend below any potential incapacitating smoke layer within the calculated RSET.*

$RSET_1$ = 5.8 minutes

Egress Path #2

Figure 104 shows Egress Path #2. This path of travel commences at the most remote corner of the industrial area identified in Balloon 49 in Figure 70. There is a short parapet wall around this industrial area that allows personnel to move on a path that is non-compliant to the requirements of Chapter 10 of Reference (b). According to the ACME Building's Safety organization, this Reference (b) non-compliant path meets the requirements for equipment as defined within the OSHA rules. This is deemed acceptable for an industrial facility. Personnel within this industrial area always exit through the east side; however, they are instructed to use whatever path is feasible in an emergency.

Egress Path #2 is 514' long and has three stairs along the path. Table 11 shows this area as having an OL of 76 people. ¼ of this OL (19 people) is assumed to be gathered at the general area at the starting point of this egress path.

The RSET and time to travel (t_{trav}) Egress Path #2 are as follows:

$t_{trav} = t_s + t_p$ *Equation 12*

$t_s = t_{st} + t_{sc}$ *Equation 12*

$t_{st} = t_{sss} * N$ *Equation 9*

t_{sss} (36" stairway) = 0.0088 minute/stair *Equation 18*

N = 3 stairs

t_{st} = 0.0088 minute/stair * 3 stairs

t_{st} =0.03 minute

$t_{sc} = t_{ssc} * L_c$ *Equation 10*

t_{ssc} = 0.0051 minute/ft *Equation 16*

L_c = 514'

t_{sc} = 0.0051 minute/ft * 514'

t_{sc} = 2.62 minutes

t_s = 0.03 minute + 2.62 minutes

t_s = 2.65 minutes.

t_p = 0.0306 * X *Equation 16*

X = 19 people

t_p =0.58 minute

t_{trav} = 2.65 minutes + 0.58 minute

t_{trav} = 3.23 minutes for exit egress travel time

$RSET = t_{det} + t_{warn} + t_{pre} + SF*t_{trav}$ *Equation 1*

$t_{det} + t_{warn} + t_{pre}$ = 2.75 minutes *Equation 1.4*

SF = 1.5 *Assumptions*

RSET = 2.75 minutes + 1.5 * 3.23 minutes

$RSET_2$ = 7.6 minutes

Egress Path #3

This path starts at the end of the crane catwalk in the main PNNRA-517 high bay. This area is only occupied for crane maintenance and for operators to access the crane control area. It is assumed that four individuals performing crane maintenance are at the end of this catwalk when an emergency evacuation is required.

The height of the crane catwalk is approximately 29' Above the Finished Floor (AFF). The ceiling height in this area is approximately 58' AFF. The MOE components have the following values:

1st Floor Distance: 193'

Crane Catwalk Distance: 195'

Number of crane access stairs: 50 [this reflects a conservative 7.5" riser, not the actual # of stairs]

t_{st} = 0.0088 minute/stair * 50

t_{st} =0.44 minute

Catwalk: t_{sc} = 0.00510 minute/ft * 195'

t_{sc} = 1 minute

1st Floor: t_{sc} = 0.0051 minute/ft * 193'

t_{sc} = 1 minutes

t_p = 0.0306 * 4 people

t_p =0.12 minute

t_{trav} = 0.44 + 1 + 1 + 0.12

t_{trav} = 2.56 minutes

*RSET = 2.75 + 1.5 * 2.56

**This location is unique due to its location with good visibility of the high bay. Personnel in this location will sense smoke through sight or smell and hear any warning shouts quickly. The worst location on the catwalk is 195' from the nearest stairway or egress ladder that will quickly lower occupants below the smoke layer. The estimated pre-movement time from this location is likely much less than the 2.75 minutes making the actual RSET for this location less than what is shown. The time to reach the catwalk access stairway or ladder from the worst location on this mezzanine is t_{ssc} = 0.0051 minute/ft * 195 ft = 60 seconds. Even with the 1.5 safety factor applied, the time to reach the stairs is 90 seconds. Personnel descending the stairs will descend below any potential incapacitating smoke layer within the calculated RSET.*

$RSET_3$ = 6.6 minutes

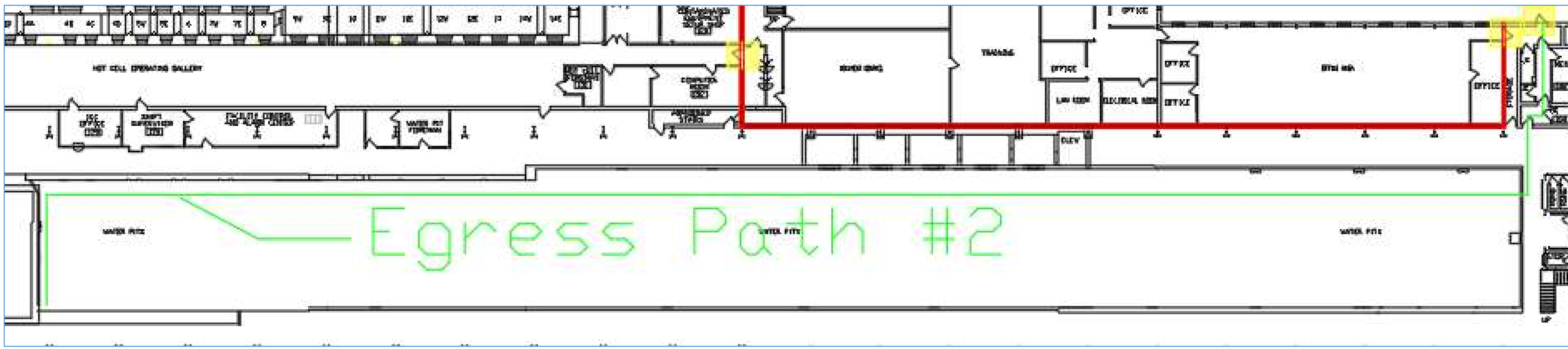


Figure 104: Egress Path #2.

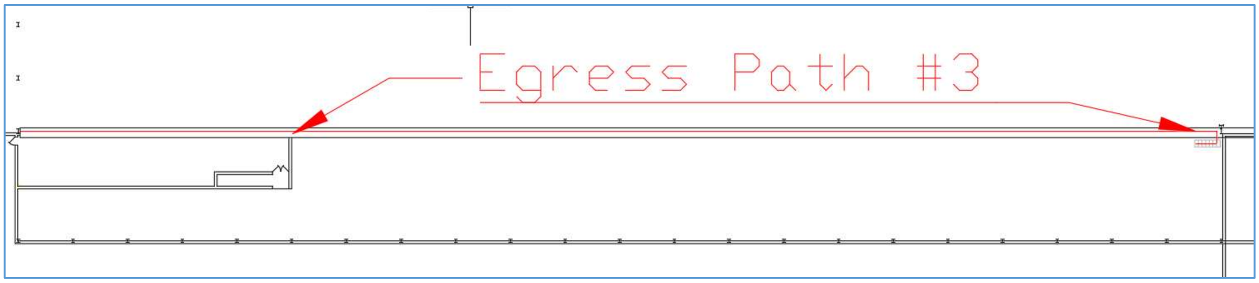


Figure 105: 2nd floor for Egress Path #3. This catwalk is above the high bay.

The catwalk is not shown in detail within Figure 105 due to drawing scaling but it is on the southside of the high bay and is about 28' from the ceiling. The egress path from the catwalk emerges from the crane access stairway on the 1st floor and proceeds through the exit access door on the south of the storage area labeled by Balloon 89 in Figure 73, which is shown in Figure 106. The path proceeds to the south and exits through the west door shown in this figure.

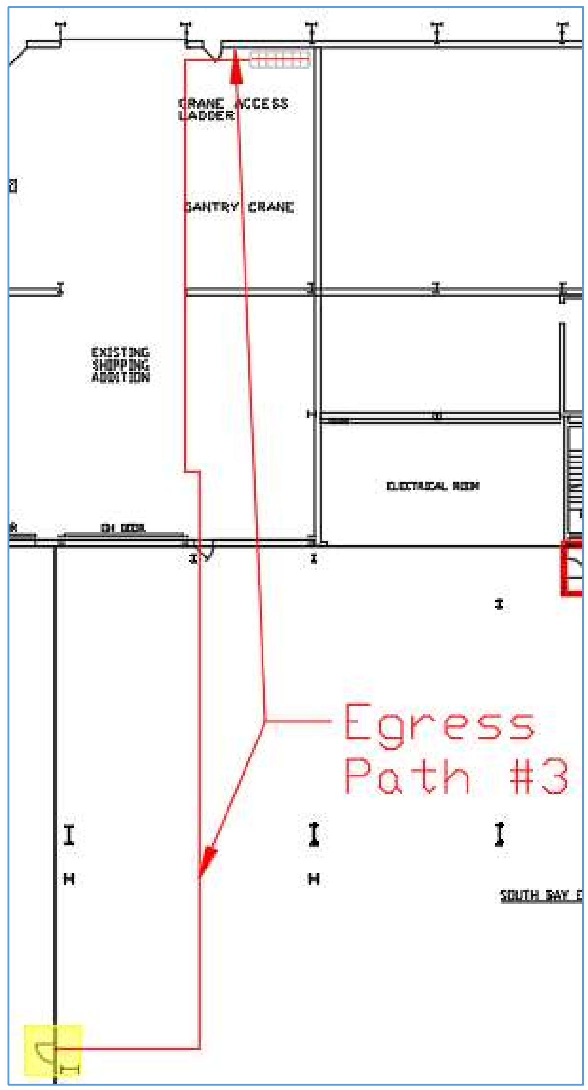


Figure 106: 1st floor for Egress Path #3.

SOFTWARE MODELING

The Pathfinder program produced by Thunderhead Engineering was used to simulate the egress of the ACME Building. A model was drawn up that represented the building but excluded small equipment areas and the crane access catwalks to simplify the drawing process. This model is shown in Figure 107. The total number of occupants applied to this building was based upon the overall occupancy load that is shown in Table 9 and Table 10. Two different egress algorithms were used for this evaluation. The Steering algorithm enables occupants to move around obstacles and attempt to optimize their routes. The other algorithm is the SFPE Hydraulic model that was used in this report for calculating RSET. The total egress time for Egress Path #2 using the Steering algorithm was approximately 4 minutes, and the SFPE algorithm was just over three minutes. Approximately 30 seconds of egress time for the Steering algorithm was due to queuing on the north central exit after all other exits were cleared. The SFPE algorithm did not have a queuing problem like the Steering algorithm. The hand calculations used in the previous section to estimate the travel time (t_{trav}) for Egress Path #2 was found to be approximately 3 minutes and 14 seconds, which is more than the software modeling value. This is likely due to the conservative assumptions for the hand-calculations, and the maximum OL used in the software model.

This model did not test Egress Paths #1 or #3 from their top elevations as the various equipment platforms and catwalks were not drawn for this simulation. The results from the locations that were simulated give strong confidence that the actual egress time from the smaller areas, such as the crane access catwalks, would have been about the same time as the other locations. This is because in the simulation Egress Path #2 vacated in approximately three minutes, the same result as the hand-calculations.

This building would never see such a large occupant load, as the volume of people simulated for this exercise is beyond what this overall campus where the ACME Building is located would ever have. The expectation is that this building is not going to hold more than approximately 300 people at any time making the Pathfinder results very conservative.

[redacted]

Figure 107: Pathfinder model of the ACME Building.

TENABILITY PERFORMANCE CRITERIA

The goal in estimating ASET is to identify the time that occupants can safely egress a building that is on fire. An ASET estimate gives to the time until occupants are exposed to untenable conditions. Four different methods for this are defined in the Annex to Section 5.2.2 of Reference (m). These four methods are used in reference to a building specific DBF and are outlined as follows:

Method 1: Occupants are not immediately incapacitated by fire effects when immersed in a toxic-gas environment. This method involves a fractional effective dose that addresses the effects of carbon monoxide, hydrogen cyanide, carbon dioxide, hydrogen chloride, hydrogen bromide, and anoxia. This method presumes that occupants will be exposed to incapacitating gases and the time for evacuation is limited by how long it takes for people to become incapacitated.

Method 2: The ASET value will require each room or area to be fully evacuated before the smoke and toxic gas layer in that room descends to a level lower than 6 ft (1830 mm) above the floor.

Method 3: The smoke and toxic gas layer will never descend to a level lower than 6 ft (1830 mm) above the floor in any occupied room.

Method 4: No fire effects will reach any occupied room.

Each of the methods outlined above requires a DBF to calculate the ASET. A DBF is based upon the general combustible environment of the building. The ACME Building has a low combustible loading and has very tight controls on flammable and combustible liquids. A rough estimate for combustible loading is on the order of less than 20,000 BTU/ft^2 for the industrial areas.

Reference (k) (page 18-7) specifies that a combustible loading of combined dead and live loads under 100,000 BTU/ft^2 is considered a low fire load, even with localized excursions up to 200,000 BTU/ft^2. The extremely low combustible loads associated with the ACME Building, including mostly non-combustible construction materials, result in a low probability that a fire can spread and impact occupants prior to their emergency egress. Trucks are occasionally brought into this building to offload materials which does result in introducing a high combustible loading into this building while the truck is parked. An engine fire or ruptured fuel tank that spreads fuel to an ignition source could potentially add a combustible situation to this facility. To avoid these situations, drain catches are staged under trucks during any interior offloading evolutions to capture any potential fuel leaks. Additionally, 100-pound portable CO_2 tanks are staged near the engine compartments of parked trucks to be used in the event of an engine fire.

The calculation of ASET will rely on Method 2, described above as quoted from Reference (m). The DBF used will be a diesel spill that is ignited and results in a pool fire. This fire scenario will rely on the HRR that a diesel pool fire will produce and will take into consideration the cooling effect that the floor will apply to a thin pool fire from an unconfined spill. Several floor obstacles will keep the fuel semi-constrained. These include the drain catch placed under truck fuel tanks, small recess areas from crane rails embedded in the floor, and storage boxes. Typically, the plywood storage boxes staged in this area contain non-combustible items. A reasonable estimate of area for this pool spill that is used to calculate toxic gases can be approximated to cover 280 square feet. Any additional combustion HRR from wood crates will be considered included within the heat of combustion of the diesel. This assumption allows the mathematical model from a steady-state pool fire to be applied to the equations that calculate smoke levels within an atrium.

The smoke layer interface position is evaluated using the procedure as defined in Chapter 51 of Reference (h). Equation 51.13 of Reference (h) is used for this evaluation for steady-state fires, as referenced below. This equation is based upon a fire away from walls, which allows for a maximum amount of smoke to be generated. A steady state scenario of a diesel pool fire will be used as the input criteria for this formula. The steady state fire will be for a 280 square foot pool fire with a constant HRR. It is assumed that after 20 gallons of fuel are consumed, the occupants will have safely exited from the area affected by this fire.

DBF 4 Fire Assumptions

- A pool fire of constant HRR will be used with diesel (fuel oil) as the fuel source.
- This model will represent a slower burning pool fire than DBF 1, which was previously analyzed for a diesel pool fire over 280 ft^2 (26 m^2). The intent for this analysis is to determine the ASET that will apply for a worst-case situation. It is reasonable to apply an approximate 40% increase in time for burning the 20 gallons of fuel to represent the cooling effect of the floor and the slow flame spread of the diesel.
- For conservatism, it is assumed that the diesel pool fire will have a 100% combustion efficiency. The typical combustion efficiency for such a fire based upon laboratory results is between 60% and 80% making this a very conservative assumption.
- The high HRR will result in no stratification within the main high bay.
- Any combustible components of the shipping truck or adjacent combustible packaging will be appropriately represented by the HRR of the diesel pool fire.
- The area of the pool fire will remain constant at 280 ft^2 (26 m^2) until all the fuel is consumed.
- A maximum of 20 gallons of diesel will represent the fuel consumed prior to occupants egressing the area. Additional analysis in this report will review the situation of fires extending past this volume.

$\dot{m}''$	= *Burn rate of fuel*
$\dot{m}''_\infty$	= *Optimal burn rate of fuel*
$\dot{Q}$	= *HRR (kw)*
Δh_c	= *Heat of Combustion*
A_f	= *Area of pool fire*
A	= *High-bay area*
H	= *Height*
SG	= *Specific Gravity of diesel (0.85)*
t	= T*ime*
t_f	= *Time for 20 gallons of diesel to completely burn at the maximum HRR*
V	= *Volume of Fuel*
Z	= *Height of smoke layer represented as 6' above the worst-case walking surface*

$\dot{m}'' = \dot{m}''_\infty$ *Equation 20 (Eq. 65.20 Reference (h))*

$\dot{m}'' = \dot{m}''_\infty$ ~~$[1-e^{-kbD}]$~~ *$[1-e^{-kbD}] = 1.0$ for $D > 2.6$ m*

$\dot{m}^{//} = \dot{m}^{//}_{\infty} = 0.035$ kg m^{-2} s^{-1} *Table 26.21 Reference (h)*
$\dot{Q} = \dot{m}^{//} * A_f * \Delta h_c$ *Equation 22 (Eq. 65.24 Reference (h))*
$\Delta h_c = 39.7$ MJ kg^{-1} *Table 26.21 Reference (h)*
$A_f = 26$ m^2 *See Assumptions*
A =71,600 ft^2 (6,660 m^2) *High-bay area*
H = 58' (17.7 m) *High-bay ceiling height AFF*
Z = 41' (12.5 m) *Allowable smoke layer depth AFF Egress Path #1*
Z = 6' (1.8 m) *Allowable smoke layer depth AFF Egress Path #2*
Z = 35' (10.7 m) *Allowable smoke layer depth AFF Egress Path #3*
INC = 140% *Increase in combustion time as specified in assumptions*

Calculating time to burn the 20 gallons with the stated assumptions
t_f = V * SG * 8.33 lbs/gallon / 2.21 lbs/kg / ($\dot{m}^{//}$ * A_f) * INC
t_f = 20 gallons * 0.85 * 8.33 lbs/gallon / 2.21 lbs/kg / (0.035 kg m^{-2} s^{-1} * 26 m^2) * 140%
t_f = 99 seconds

Calculating the maximum HRR for a diesel pool fire that is 280 ft^2 (18.5 m^2)
$\dot{Q}$ = 0.035 kg m^{-2} s^{-1} * 26 m^2 * 39.7 MJ kg^{-1} * 1000 kW/MW / INC
$\dot{Q}$ =25,800 kW

Calculating the height above the finished floor level of the high-bay for the smoke layer

$$\frac{Z}{H} = 1.11 - 0.28 \ln\ ([t\,\dot{Q}^{\frac{1}{3}} H^{-\frac{4}{3}}]/[\frac{A}{H^2}])$$ *Equation 23 (Eq. 51.13 Reference (h))*

$$Z(t) = H * (1.11 - 0.28 \ln\ ([t\,\dot{Q}^{\frac{1}{3}} H^{-\frac{4}{3}}]/[\frac{A}{H^2}]))$$

$$Z(99)\ = 17.7\ * (1.11 - 0.28 \ln\ ([99 * 25{,}700^{\frac{1}{3}} 17.7^{-\frac{4}{3}}]/[\frac{6{,}660}{17.7^{\ 2}}]))$$

Z (99) = 14.2 m

The maximum smoke layer is estimated to be 14.2 meters (47') AFF from a diesel pool fire burning at the maximum possible HRR over a 280 ft^2 area for 99 seconds. This corresponds to 20 gallons being burned. The crane access catwalk is 29' above the floor. This fire would result in a smoke layer that is 18' above the catwalk, which would enable personnel to safely egress under the smoke layer. Based upon the assumptions listed above, personnel will be able to safely egress from all locations in the ACME Building for this fire scenario.

The following three subsections evaluate the time for tenability if the fire continued to burn past the 20-gallon limit due to additional fuel spilling into the pool fire.

For Egress Path #1 ($RSET_1$ = 5.8 minutes):
41 feet (12.5 meters) is the allowable smoke layer height for Egress Path #1 for occupants to safely egress. This height is defined as six feet above the 35 foot high fan-room mezzanine location.

$$12.5\ = 17.7\ * (1.11 - 0.28 \ln\ ([t * 25{,}700^{\frac{1}{3}} 17.7^{-\frac{4}{3}}]/[\frac{6{,}660}{17.7^{\ 2}}]))$$

Solving for "t" which is ASET:

*ASET = 140 seconds (2.3 minutes) *[this time for an elevated location and increases as the population descends]*

**This location is not directly affected by the DBF in the main High-bay. The Hot Cell Loading Area (HCLA) that is used to access the fan room where this elevated mezzanine is located is separated from the high bay by a large wall that will block some smoke from entering this location. The HCLA does not have vehicle access and has limited combustibles. Only diluted smoke will enter the HCLA until the smoke layer reaches <20’ above the floor, at which point it will enter this area and build up at the ceiling. This adds significant smoke filling capacitance. The ASET value for Egress Path #1 needs to add time because of this situation. A conservative time is to add the ASET time of Egress Path #3, evaluated below, with a safety factor of 2. That provides an additional 3.4 minutes / 2 = 1.7 minutes = 102 seconds of additional ASET for this path.*

ASET = 140 seconds + 102 seconds (2.3 minutes + 1.7 minutes)
ASET = 242 seconds (4 minutes)

For Egress Path #2 ($RSET_2$ = 7.6 minutes):
Six feet (1.8 meters) is the allowable smoke layer depth AFF for Egress Path #2. This is six feet above the high-bay floor where the design basis fire is being modeled.

$$1.8 = 17.7 * (1.11 - 0.28 \ln ([t * 25{,}700^{\frac{1}{3}} 17.7^{-\frac{4}{3}}]/[\frac{6{,}660}{17.7^{2}}]))$$

Solving for “t” which is ASET:

ASET = 1,210 seconds (20.2 minutes)

For Egress Path #3 ($RSET_3$ = 6.6 minutes):
35 feet (10.7 meters) is the allowable smoke layer depth AFF for Egress Path #3. This height is six feet above the 29 foot high crane access catwalk, which overlooks the high-bay where the fire is being modeled.

$$10.7 = 17.7 * (1.11 - 0.28 \ln ([t * 25{,}700^{\frac{1}{3}} 17.7^{-\frac{4}{3}}]/[\frac{6{,}660}{17.7^{2}}]))$$

Solving for “t” which is ASET:

ASET = 202 seconds (3.4 minutes) [this is for the catwalk location and so the available time increases as the population descends]

RSET vs ASET Determination
The calculated RSET values for Egress Path #1 and #3 shown above are higher than the overall ASET time values. The RSET values are calculated at the starting elevation for these two egress paths. As personnel descend lower than their starting locations, the ASET values steadily increase at a rate of approximately nine seconds per vertical foot based upon Equation 23. This is because smoke rises while the people are descending, which creates more available time for safe egress.

The time personnel take to lower themselves while descending on stairs is evaluated from Equation 18:

Time = 0.0088 minute/stair * 1 stair/7.5” * 12” / 1 ft * 60 sec / minute
Time = 0.85 second per foot in elevation reduction.

This shows that personnel can descend approximately 10.6 times faster (nine seconds / 0.85 second) than the smoke can descend. This is why the Egress Paths #1 and #3 are tenable.

Evaluating Egress Conditions
The DBF scenario used in this analysis is conservative. The diesel pool fire used in this DBF would be thin and be cooled by the floor resulting in a much lower HRR than the maximum used for this example. Furthermore, the flame spread velocity for diesel is slow, resulting in additional warning time for personnel to be notified.

The 20 gallons of diesel that is used to represent this DBF is an approximation for a worst-case situation for this area, as the general lack of combustibles will likely keep a fire from consuming more than this amount of equivalent fuel loading. If a fire does continue past this 20-gallon limit, such as a fully engulfed truck, including its 50-gallon fuel tank, tenability for Egress Paths #1 and #3 is questionable using Method 2 for tenability from Reference (m) as described above using such a large pre-evacuation time. As discussed, the pre-evacuation time used (2.75 minutes) is conservative for the ACME Building population and does not reflect the actual immediate responses personnel have shown through drills. As evaluated above, tenability for a continuing fire (not restricted to 20 gallons of diesel) will be limited to 3.4 minutes (202 seconds) for the crane access catwalks (worst situation of the three Egress Paths analyzed) using Method 2 from Reference (m) as described above. The travel time for the catwalk (t_{sc}), excluding the safety factor, as evaluated above for Egress Path #3 in the RSET section of the "Emergency movement Components of Evacuation Time" section of this report showed a travel time of 1 minute to safely walk the maximum length of the crane access catwalk to reach the stairway (or ladder) that will lower occupants below the smoke layer. As tenability for the crane access catwalk is shown as 3.4 minutes (202 seconds), it is assumed the personnel will safely arrive at the stairway or ladder prior to being immersed in the smoke layer. With the safety factor of 1.5 applied to the catwalk travel distance and adding that to the pre-evacuation time (2.75 minutes), the maximum time to reach the stairway will be 2.75 minutes + 1.5 * 1.0 minute = 4.25 minutes, which exceeds the ASET value of 3.4 minutes, making this egress path untenable using Method 2 without modifications to the assumptions and limiting the conservatism of the safety factors.

It is assumed that if a fire this large occurred, occupants in the vicinity of the fire would be warning personnel loudly to exit immediately. Egress Path #1 would require roughly 20-feet to reach the stairway that would bring these occupants to a lower level that would be clear of smoke, which is why Egress Path #3 is a bounding location and Egress Path #1 is assumed to be able to safely egress in a worst-case situation. Egress Path #3 is on a catwalk that has a wide view of the high-bay area, and occupants on the catwalk would hear the floor personnel making notifications and see smoke resulting in a very quick pre-movement time. In a real-world situation, due to the sense of urgency, this small number of occupants would be able to access the stairway prior to the smoke lowering below the six-feet limit above the crane access catwalk.

Table 13: Incapacitation Analysis for Diesel Smoke.

Steady State Analysis Based Upon Data from Table 7.8 in the GHBF for a Well Ventilated Fire with Victim in Room of Origin												
Time (min)	1	2	3	4	5	6	7	8	9	10	11	12
CO ppm	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
CO2 %	5	5	5	5	5	5	5	5	5	5	5	5
O2% 20.9*(1-%CO2/100)	19.855	19.855	19.855	19.855	19.855	19.855	19.855	19.855	19.855	19.855	19.855	19.855
F(I-co) (3.317*10^-5*CO^1.036 * V/D)	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073
V(CO2) EXP(0.1903*%CO2+2.004)/7.1	2.706	2.706	2.706	2.706	2.706	2.706	2.706	2.706	2.706	2.706	2.706	2.706
%COHb/m (3.317*10^-5*CO^1.036*V*V(CO2))	5.900	5.900	5.900	5.900	5.900	5.900	5.900	5.900	5.900	5.900	5.900	5.900
%COHb	5.900	11.800	17.700	23.600	29.500	35.400	41.300	47.200	53.100	59.000	64.900	70.800
F(I-co) * V(CO2)	0.197	0.197	0.197	0.197	0.197	0.197	0.197	0.197	0.197	0.197	0.197	0.197
F(I-o2) 1/EXP(8.13-0.54*(20.9-%O2))	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
F(I-CO2) 1/EXP(6.1623-0.5189*%CO2)	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
Total F'(IN)	0.225	0.225	0.225	0.225	0.225	0.225	0.225	0.225	0.225	0.225	0.225	0.225
Running total	0.225	0.451	0.676	0.902	1.127	1.352	1.578	1.803	2.029	2.254	2.479	2.705

An incapacitation analysis performed for the assumed type of smoke that would be emitted by this DBF shows that there are approximately four minutes that people can breathe this smoke before incapacitation renders them unconscious. Table 13 shows this analysis that was developed using the method shown in Chapter 7 of the SFPE Guide to Human Behavior in Fire, 2nd edition, Reference (l). The Carbon Monoxide (CO) levels were taken from Table 7.8 of Reference (l) and are approximate.

Humans will typically be rendered incapacitated when their blood has a Carboxyhemoglobin (COHb) level of 30%. Other incapacitating factors such as hypoxia and high levels of CO_2 contribute to this value. The table above calculates incapacitation factors (F(Io2), F(I-CO_2), F(I-co)) and sums these together. When these capacity factors exceed "1," incapacitation is likely. As highlighted in this table, the incapacitation level is reached in approximately four minutes after starting to breath from this smoky environment.

Applying a Safety Factor (SF) of four to this time reduces the time someone can breathe in this smoke-filled environment down to one minute before incapacitation. It is reasonable to apply this large SF to the incapacitation time to make up for incapacitation factors that are difficult to quantify in this analysis, such as hydrogen cyanide, hydrogen chloride, and hydrogen bromide contributions from truck upholstery and miscellaneous components. This safety factor is also used to make up for the potential physiological weaknesses of certain employees.

Adding this additional 60 seconds of available egress travel time, as permitted per Method 1 as described above from Reference (m), increases the available pre-movement and travel time from 202 seconds to 262 seconds (4.4 minutes) to reach the stairway or ladder to egress from the crane access catwalk. Even with the assumption of the conservative 2.75-minute pre-evacuation time, and with the 1 minute * 1.5 safety factor catwalk walking time, personnel will be able to safely drop below the smoke layer before incapacitation (4.25 minute < 4.4 minute).

The equipment platform locations evaluated for Egress Paths #1 and #3 are not considered normally occupied but provide a bounding analysis that proves all other locations will be safe in the event of a worst-case fire. As an example, the 2nd floor business area on the Northside of the ACME Building has a floor height of approximately 12-feet above the first floor. The Z-value (allowable smoke layer) for this location is 18-feet (5.5 m) in the high-bay. The ASET value that corresponds to this height as evaluated by Equation 23 for a High-bay fire is 580 seconds (9.7 minutes), which exceeds the worst-case of 6.1 minutes that was calculated for Egress Path #3, including the additional pre-movement time, and added safety factor. Furthermore, ASET for Egress Path #2 was shown to be more than 20 minutes. This time can be applied to all of the first floor due to the large height of the high bay that provides capacitance for the accumulation of smoke. Additionally, random surprise fire evacuation drills in this building have shown occupants completely evacuating, frequently within two minutes. This provides additional verification that occupants would be safe from this conservative fire example as personnel even in the worst locations can reach lower elevations in time to safely breath.

Fires occurring in other locations, such as in the business occupancy portions of the ACME Building, will be controlled by the suppression system and enable personnel to safely egress. The limited combustibles in the ACME Building business occupancies categorize the area as light combustible loading, while the sprinkler system in the area is sized for Ordinary Hazard levels, exceeding the requirements and able to suppress much higher levels of combustible loading.

This report did not analyze the RSET or ASET for the observation room found under the north beach of PNNRA-517, nor any process related pits. The large high-bay environment over these locations provides smoke-capacitance that will provide an abundance of time for safe egress. The calculated ASET value using Reference (h) Equation 51.13, which is calculated at more than 20 minutes for Egress Path #2 in the high bay, establishes that these below grade locations will support safe egress. Further analysis will be performed on the ASET for the high bay in the next section of this report that will show a lower value than the 20 minutes for ASET. Although lower, this will be shown not to impact the overall conclusions regarding occupants being able to safely egress.

The calculated ASET times calculated above relied on equation 51.13 of Reference (h). Additional validation of the ASET results was performed using Fire Dynamics Simulation (FDS) software which relies on computational fluid dynamics calculations via a high-speed computer to calculate actual smoke and fire behavior in a test-fire situation. The nature of the DBF involving the 200 ft^2 diesel pool fire, which was calculated above, resulted in an HRR of approximately 25 MW. This DBF needs further validation from an actual truck fire to ensure the assumptions made will still render conclusions that keep personnel safe. A pool fire was used in the above calculations so that Equation 51.13 of Reference (h) could be used due to the need for a steady-state HRR for that equation. FDS does not require such a steady-state fire, so a more realistic fire can be used to calculate ASET.

Truck Fire Analysis Using FDS

The parked truck evaluated in this DBF is located on the west side of the PNNRA-517 high bay of the ACME Building. This analysis performs fire modeling to characterize what happens if the actual truck ignites.

Figure 108: Truck fire location.

There is no applicable published truck-fire related HRR data that appropriately models the truck that is likely to be parked at the location shown above in Figure 108, so assumptions are made from other large scale vehicle tests. Reference (h) provides an HRR data profile for a school bus [Reference (h) Figure 26.94], which provides an upper boundary in terms of HRR for an expected semi-truck fire. Additionally, a 2019 journal article, "Experimental Study on the Fire-Spreading Characteristics and Heat Release Rates of

Burning Vehicles Using a Large-Scale Calorimeter," Reference (n), published at www.mdpi.com provides data for car fires. For the characterization of this DBF, a lower and upper boundary is defined to help characterize fire performance and sprinkler activation. The lower boundary condition for HRR applied for this DBF is for two sedans simultaneously on fire, while the upper boundary is for a school bus fire. This HRR profile is shown in Figure 109.

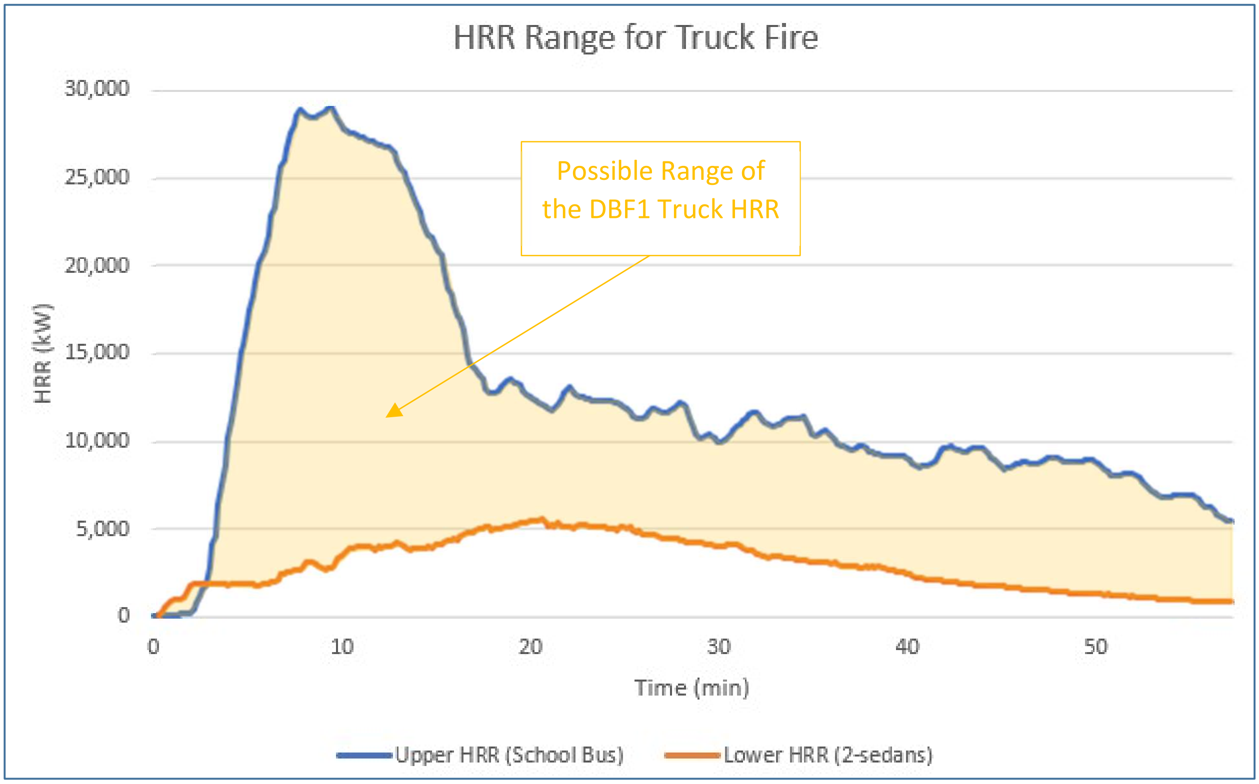


Figure 109: HRR range for truck fire DBF.

The school bus HRR is a reasonable upper boundary for the truck being modeled. The expected combustible loading in a school bus is higher than what is expected in the DBF truck. This is because the transported load on this truck and trailer has combustible crating with minimal combustible contents within the crates. The bus example has several upholstered seats with foam cushioning. It is reasonable to assume the bus HRR is an upper boundary for combustible loading and heat release during a fire.

Two sedans burning simultaneously are expected to be a low estimate for the potential HRR from the fire. The combined volume of the fuel tanks of the sedans will be only about 60% of the volume of diesel fuel that is possible within the truck; however, the truck diesel fuel has a lower flame spread speed than the sedans' gasoline. Although the heat of combustion for the fuels are about the same, in the event of a pierced tank, it is expected that the gasoline will burn faster than the diesel as the flash point for gasoline is approximately 90° C lower than diesel and the combustion rate of gasoline is approximately 57% faster than diesel fuel [Table 26.21 Reference (h)]. Other factors include more foam cushioning and upholstery in the sedans' interior than the truck, although the truck does have more rubber content in its tires. Regardless, the lower value is an estimate that bounds a likely scenario, while the upper value bounds a worst-case scenario for the truck fire.

Products of Combustion

Page 359 of "An Introduction to Fire Dynamics, 3rd edition," Reference (o), specifies that levels of carbon monoxide (CO) of up to 6% (60,000 PPM) can flow from the room of origin through an open door into the rest of the building during the period immediately preceding flashover. The truck fire characterized in this section will experience flashover conditions within the cab, but the overall products of combustion at the level of the crane operator catwalk can reasonably be estimated at 0.2% CO as reflected in Table 13 due to air entrainment and mixing. Soot yield is estimated at approximately 2% for this truck fire. The same conclusions from the analysis performed above for incapacitation are applied in this section. There is no reason to conclude that products of combustion from a truck fire will render personnel on the catwalk incapacitated in under the one-minute timeframe estimated above.

Tenability for the crane operators is the main purpose for this DBF. Crane operators within the high-bay crane booth will see any initiation of fire and will likely be the first to see any smoke from a truck fire. The high-bay volume is on the order of millions of cubic feet and will absorb and diffuse the smoke before creating an untenable smoke layer that will affect egress.

Figure 110: FDS results for the worst-case high-bay truck fire.

The ASET value previously calculated from Equation 51.13 of Reference (h) predicted around 20 minutes for the high bay to fill with smoke to a level that is six feet above the main floor using the 25 MW diesel spill fire covering 280 ft^2 with a prolonged burn. That ASET is longer than the ASET calculated from FDS that is demonstrated in Figure 110. Figure 110 is a representation of the 60-foot tall by 1,000 foot long high-bay as viewed from the north side of Figure 108. The reason that the FDS generated ASET is shorter is that Equation 51.13 of Reference (h) models an atrium like an upside-down bathtub that has a descending smoke layer fed from the design fire. The 280 ft^2 diesel pool fire previously used to analyze ASET in the high bay produced a continuous HRR of 25 MW. The fire used in FDS that provided the results shown in Figure 110 relied on the HRR profile shown in Figure 109. The 25 MW 280 ft^2 continuous pool fire is hotter than the average of the worst-case fire model shown in Figure 109. Although the PHRR for the worst-case modeled fire shown in Figure 109 is 31 MW, the HRR profile does not exceed 25 MW until over seven minutes after the truck fire starts. This means that the diesel pool fire is a worst-case scenario in comparison to the worst-case truck fire that is modeled for predicting egress conditions for occupants. The FDS simulation in Figure 110 for the worst-case truck HRR shown in Figure 109 shows the ceiling jet going from the west side to the east side of the high bay. The behavior of the smoke mimics what would be observed in a long corridor where smoke moves along the ceiling until it hits the end of the corridor and then returns. This is different than the normal atrium smoke-filling scenario where smoke pours upward into an atrium and slowly lowers the overall smoke layer interface. In the case of the PNNRA-517 high bay, the dimensions are simply a scaled-up version of a standard corridor resulting in smoke behavior that is not adequately modeled by Equation 51.13 of Reference (h). Regardless of how ASET is calculated, the ASET value for either method for smoke filling shows that the upper layer of the smoke is sufficiently high so as not to impede occupants on the crane access catwalk from safely egressing.

Additional FDS and Hand Modeling that Ensures Safe Egress
FDS modeling was performed at two additional locations to better characterize ASET values. These locations are shown below:

Figure 111: Locations for the two FDS modeled workstation fires.

The location at the bottom left (southwest) of Figure 111 is a storage area that is 16,000 ft^2 (PNNRA-117). There are multiple exits from this location, but FDS is used to model a fire at this location to measure the smoke layer level to confirm occupants can safely reach an exit door. FDS is used due to the sloped ceiling in this area that makes standard hand calculations imprecise.

The other workstation fire is modeled in an office compartment on the top right (northeast) side of this facility next to an open exit access stairway that connects the first and second floors that are used for office related work. There are two first-floor corridors that intersect at this office location so smoke can travel through either of these corridors or rise through the open exit access stairway into the second floor's main corridor. FDS is used to characterize the smoke layer for these three corridor locations.

<u>HRR Modeling:</u>

These two additional FDS simulations are based upon a trashcan fire that is ignited by a defective personal electric heater near a desk area. The trashcan is modeled as a seven-gallon repository that contains crumbled paper and water bottles and is adjacent to other combustibles. Those adjacent items include the following:

1) A Shopvac with about 120 grams of debris that is about 0.2 m away from the trashcan.
2) A 17.5 kg upholstered chair that is 0.1 m away.
3) The worst-case workstation HRR data from the University of Maryland's Burning Item Database, Reference (p).

The HRR profile for this trashcan is defined in Test 91 from the National Institute of Standards and Technology (NIST) on-line Fire Calorimetry Database, Reference (q), and is shown in Figure 112.

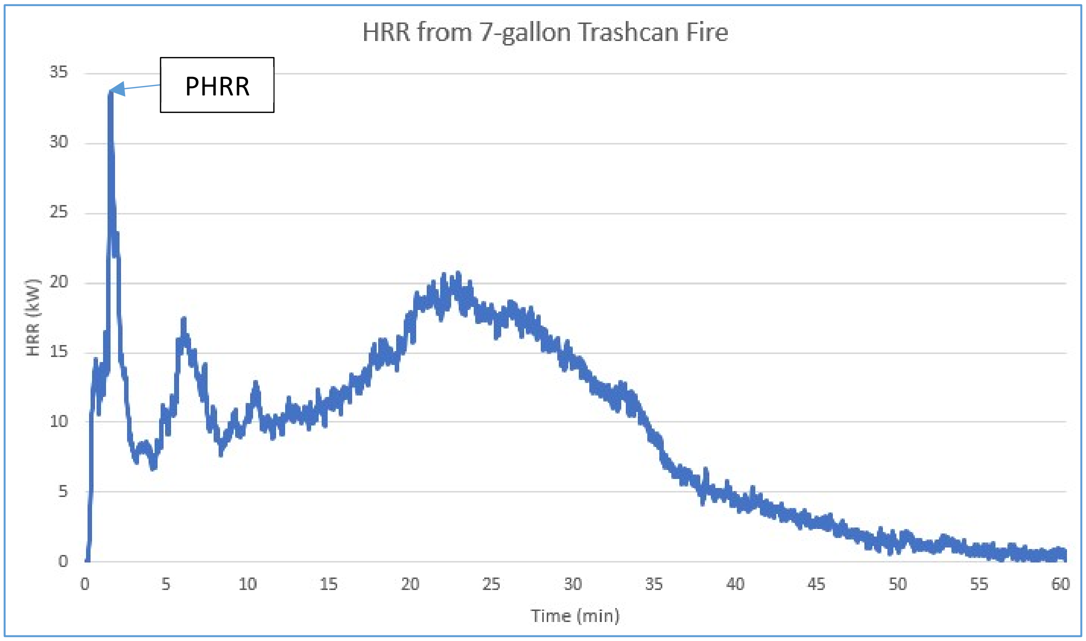


Figure 112: HRR profile for a trashcan.

This trashcan fire acts as a source of thermal radiation that causes the fire to spread. The point-source equation for incident radiative heat flux is used for this analysis to simplify the calculations. This method is only valid for targets that are a distance of more than the diameter of the fire away from the fire. The following is the point-source equation:

$$\dot{q}'' = \dot{Q}_r \mathrm{Cos}(\theta) / (4\pi R^2)$$ [Reference (h) Eq. 66.12]

The radiative fraction for this fire is 30%, with the remaining 70% of the energy produced by the fire dissipating through the smoke plume. Fire spread in this case will be predicted based upon the radiative portion of the energy.

The PHRR from Figure 112 is approximately 33 kW. Both the Shopvac and the upholstered chair are perpendicular to the trashcan fire (Cos(θ)=1). The chair is 100 mm (4") away and the Shopvac is 200 mm (8") away. Using these values, the heat flux experienced by the upholstered chair and the Shopvac as calculated by the point-source formula are as follows:

Upholstered Chair:
$\dot{q}'' = 33\ kW * 0.3 * 1 / (4\pi 0.1^2)$
$\dot{q}'' = 79\ kW/m^2$

Shopvac:
$\dot{q}'' = 33\ kW * 0.3 * 1 / (4\pi 0.2^2)$
$\dot{q}'' = 20\ kW/m^2$

These calculated heat flux values are likely lower than the actual exposure as the distance from the fire to the targets are under the diameter of the fire. Regardless, the calculated values are reasonable to use in this analysis. The Critical Heat Flux (CHF) for the upholstered chair is estimated at 20 kW/m^2. The Shopvac's casing is made from High Density Polyethylene and has an estimated CHF of 15 kW/m^2 [Reference (h) Table A.35].

Typically, there is a non-linear time lag between an applied heat flux and ignition based upon the model:

$$\frac{1}{\sqrt{t_{ig}}} = \frac{(\dot{q_c}'' - CHF)}{TRP}$$ [3.1.8.1 Professional Engineering Ref. Handbook V 1.0, Reference (r)]

t_{ig} is the time to ignition, $\dot{q}_c''$ is the applied heat flux, CHF is the Critical Heat Flux and TRP is the Thermal Response Parameter in the above formula. For this analysis, it is conservatively assumed that combustion will be initiated once the CHF is reached by the incidental heat flux from the trashcan fire. Based upon that conservative assumption, the combined HRR profile is assembled that includes the trashcan HRR values shown in Figure 112, the Reference (q) data for the Shopvac (test 49) and the Reference (p)

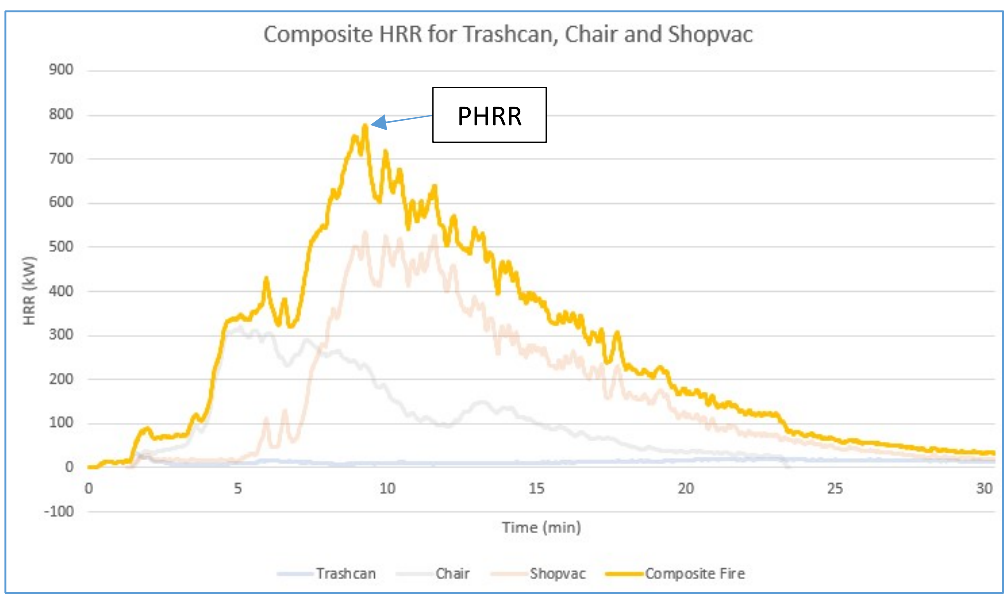


Figure 113: Composite HRR.

test data for the upholstered chair. The composite fire from these three contributors is shown in Figure 113.

The PHRR of approximately 750 kW is shown in Figure 113. This provides enough heat flux to adjacent combustibles that ignition is likely to spread in most office environments. For this analysis, a workstation is on the opposite side of the ignited upholstered chair and includes two more upholstered chairs. The workstation area is expected to ignite shortly after the first upholstered chair ignites. Figure 114 shows the combination of all fire contributors in this scenario that produces a final composite HRR.

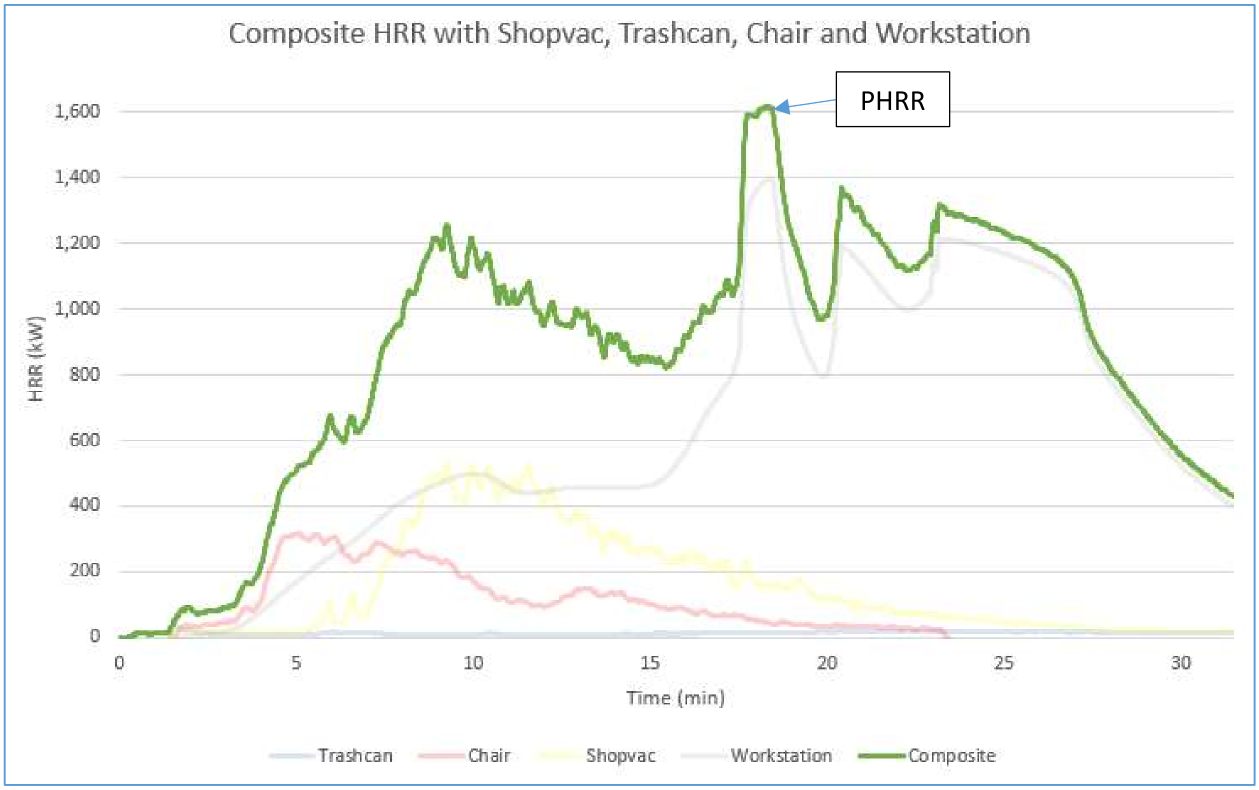


Figure 114: Composite HRR that includes the Workstation.

The estimated soot production from this composite fire is derived from the National Fire Research Laboratory (NFRL) data through Reference (q) as shown below:

Table 14: NFRL test soot yield data organized by PHRR and combustible type.

NIST/NFRL Test Data for Specific Items		
Test Description	Soot Yield	PHRR (kW)
Janitors Mop Bucket and accessories: Cellulose and Plastic.	0.421%	66.5
Bag of Personal Protection Equipment (PPE) including 8 Tyvek Suits and gloves	0.363%	115
Shop Vac with 280 g of debris. No hose.	0.555%	534
New 5 pack Tyvek suit and gloves on shelf	0.627%	72
8 cardboard boxes of crinkle paper	0.051%	2,581
7-gallon trash can with paper and water bottles.	0.129%	33

Based upon the soot yield measurements in Table 14, a conservative bounding value of 2% (gram soot/gram combustible) soot yield is used in FDS for calculating smoke density.

Tool Room FDS Analysis

The fire location within the Tool Room (PNNRA-117) at the southwest portion of the ACME Building is located as shown in Figure 115.

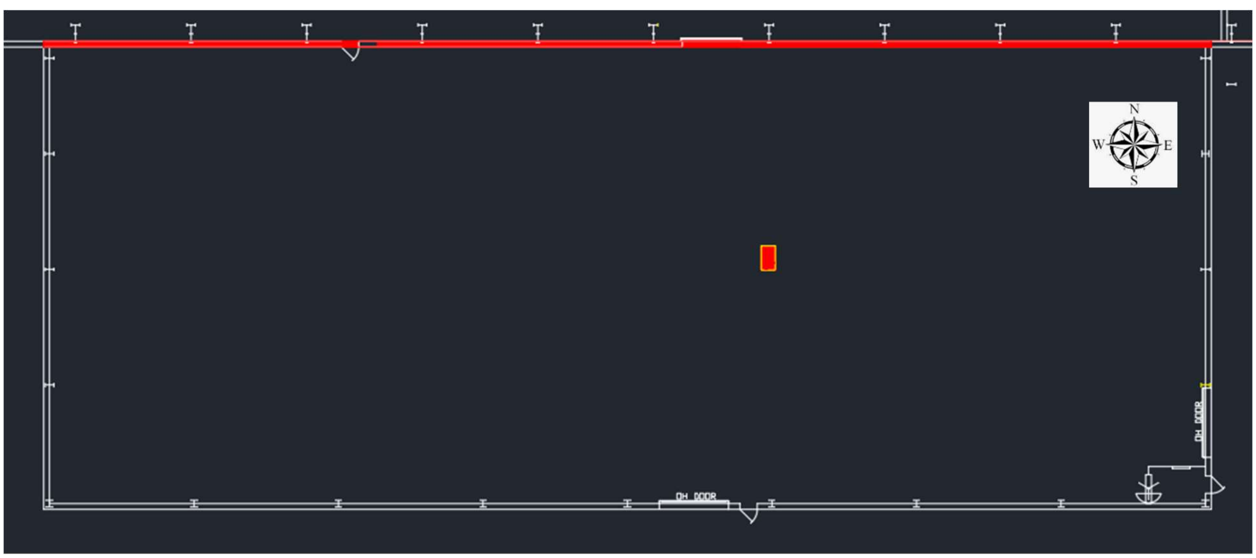


Figure 115: Location of fire in Tool Room.

Although the ceiling slopes considerable from the south to the north sides, the ceiling height where the fire is located is approximately 20’ above the floor. There is one 10-foot-high roll-up door that acts as a horizontal exit on the north side of the fire. There are three other exits in this area, along with another roll-up door to the south.

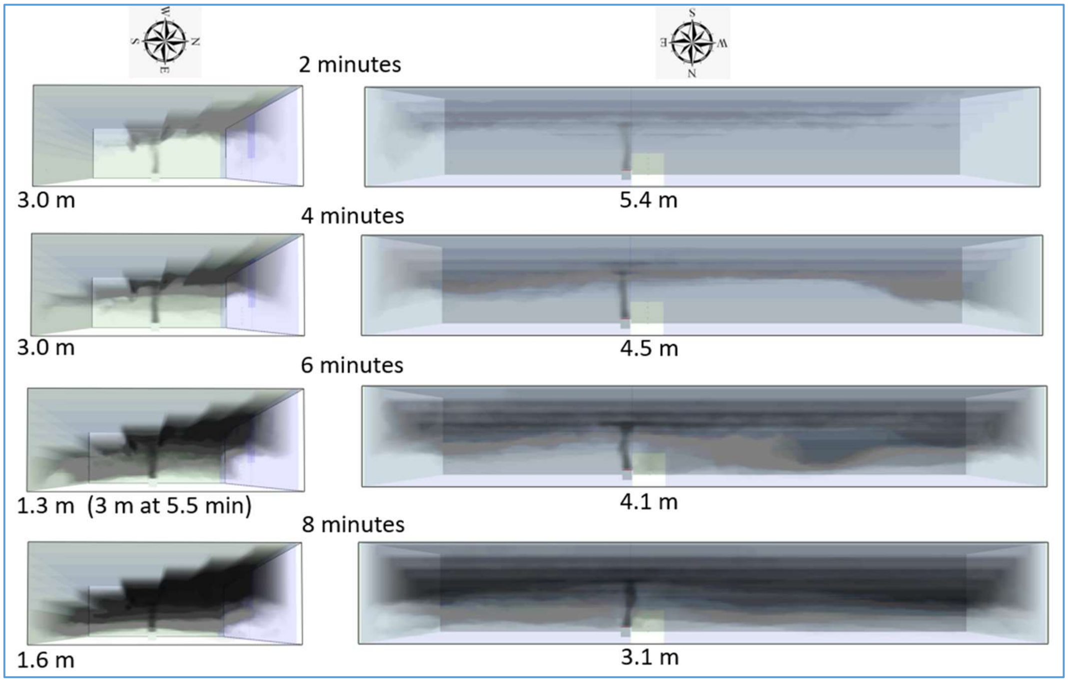


Figure 116: FDS results for the PNNRA-643 fire.

The FDS results using the composite HRR for the composite workstation fire shown in Figure 114 is illustrated in Figure 116. The estimated travel time to an exit from any location within PNNRA-117 is about one minute. As can be seen from Figure 116, the smoke layer height remains above six-feet at most locations until after 8 minutes of burn time. Some of the exits will be blocked by smoke after 5.5 minutes, but all occupants should be safely out of this facility prior to the smoke reaching the critical height of six-feet above the floor.

Office Compartment Fire Analysis

This analysis includes both the FDS analysis using the composite HRR profile shown in Figure 114 as well as hand calculations to help bound a worst-case fire scenario for the office compartment shown in Figure 111 at the northeast side of the ACME Building.

This office location has books in open cabinets and files contained within six-sided metal file cabinets. Its contents include a particle board desk with a Formica coating, two upholstered chairs that use foam cushioning and other miscellaneous ignitable items. The general computer workstation and combustible loading on the table approximately matches the workstation fire tests characterized in the Reference (p) database. The composite HRR profile will be used to find the expected rise time for a fire in this compartment. Other accepted correlations will be used to determine the required flashover HRR and burnout time.

There are three principal methods used in evaluating the average minimum HRR required for flashover conditions in a compartment. These are the Thomas Model, the Babrauskas model and the McCaffrey, Quintiere, and Harkleroad (MQH) correlation. The MQH usually yields a flashover HRR value that is below the Thomas model but requires the calculation for the heat transfer coefficient of the compartment's surfaces. The calculation of the heat transfer coefficient introduces additional unknowns because properties of the compartment surfaces need to be well characterized. The Babrauskas model is not considered accurate but provides a quick means of calculating a rough estimate for flashover conditions. This analysis will use the Thomas model and the Babrauskas method to calculate the minimum HRR for flashover.

Thomas Model

$\dot{Q} = 7.8\ A_T + 378\ A_o\ H_o^{1/2}$ (kW) [Reference (h) Eq. 30.75]

A_T = Total area of the compartment-enclosing surfaces (m^2) (minus A_o, but including floor area)

A_o = Area of Opening (m^2)

H_o = Height of Opening (m)

The office compartment is being modeled using the following properties:

- 10' (3 m) X 15' (4.5 m) X 10' (3 m) high.
- It has a single door that is 83" (2.1 m) high and 35" (0.9 m) wide.
- The combustible loading is estimated to be 50,000 BTU/ft^2 (570 MJ/m^2).
- The Heat of Combustion of the combustible loading at this location is approximately 9,000 BTU/lb (21 MJ/kg).

Using the above values, the Thomas model gives the following:

$A_O = 2.1m * 0.9m$

$A_O = 1.9\ m^2$

$A_T = (3m * 4.5m) * 2 + (3m * 4.5m) * 2 + (3m * 3m) * 2 – (2.1m * 0.9m)$

$A_T = 70.1\ m^2$

$H_o = 2.1\ m$

$\dot{Q} = 7.8\ A_T + 378\ A_o\ H_o^{1/2}$

$\dot{Q} = 7.8 * 70.1\ m^2 + 378 * 1.9 * 2.1^{1/2}$

$\dot{Q}$ = 1,600 kW

The Babrauskas correlation shows the following:

$\dot{Q} = 750 * 1.9 * (2.1\ )^{1/2}$

$\dot{Q}$ = 2,000 kW

The boundary requirement for the Babrauskas correlation requires the following condition to be met:

$A_T / (A_o/H_o^{1/2}) \simeq 50$ [Reference (h) Pg. 1,019].

$70.1 / (1.9/2.1^{1/2}) = 53$ so this correlation is appropriate.

The data used in deriving the flashover equations used above represents a range of HRR values depending on the geometry and commodity classification of the materials within compartments [Reference (o), Page 366]. Babrauskas also identified a minimum value for flashover as follows:

$\dot{Q} = 600\ A_oH_o^{1/2}$ (kW) (minimum) [Reference (h) Eq. 30.67]

The above correlation gives $\dot{Q}$ = 1,650 kW, which correlates well with the Thomas model. The analysis for this compartment office space will use the Thomas value as the appropriate low estimate for flashover conditions.

The time to burnout is estimated at:

$t_{BO} = M_f / R$ [CalPoly handout]

$R = 0.1A_OH_O^{1/2}$ [CalPoly handout]

$H_0 = 2.1$ m [Height of door]

$R = 0.1 * 1.9\ m^2 * (2.1\ m)^{1/2}$

R = 0.28 kg/s

$M_f = e_f * A / \Delta H_c$ (kg) [Mass of Fuel Reference (j) Eq. 3.12]

$e_f = 570\ MJ/m^2$ [Fuel loading]

ΔHc = 21 MJ/kg [Heat of combustion]

A (floor area) = 3 m * 4.5 m

$M_f = 570\ MJ/m^2 * (3*4.5)\ m^2 / 21\ MJ/kg$

$M_f = 366$ kg

t_{BO} = 366 kg / 0.28 kg/s = 1,307 seconds

t_{BO} = 22 minutes

The Thomas model provides the estimated minimum HRR for flashover conditions. The maximum estimated HRR within a compartment in flashover conditions [Equation 38.2 of the Reference (h)] is below:

$\dot{Q} = 1400A_OH_O^{1/2}$

$\dot{Q} = 1400 * 1.9 * 2.1^{1/2}$

$\dot{Q}$ = 3,850 MW

Although the Reference (p) Workstation data provides HRR curves for typical workstation fires, there is benefit in seeing a range of potential fires. The Reference (p) data is used to provide an estimated growth curve for a typical workstation environment. Figure 117 and Figure 118 show the initial HRR for the two workstations with a fitted model relying on the αt^2 growth relationship.

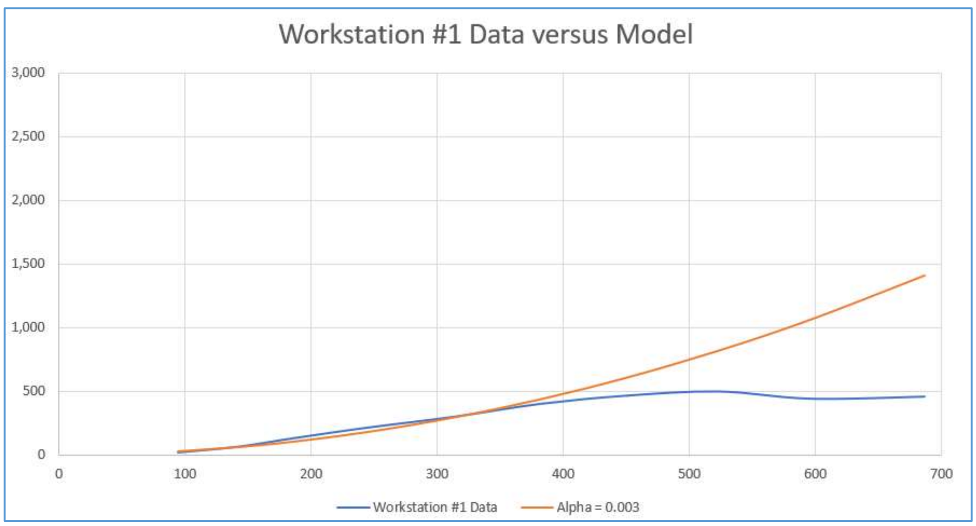


Figure 117: HRR (kW) over time (s) for Workstation #1 and the αt^2 model with the α value of 0.003 kW/s² used. Ordinate is HRR (kW), and abscissa is time (s).

As can be seen, the fire growth αt^2 model represents a conservative estimate for the growth phase of a typical workstation in a compartment. It is expected that the compartment fire will more closely follow the lower of the two models (Figure 117) as the office area being analyzed uses 6-sided metal cabinets for files and office supplies and relies on Class A interior finish. Additionally, there is an administrative policy that is actively enforced within this office space that attempts to minimize combustible loading as much as is practicable.

Figure 118: HRR (kW) over time (s) for workstation #2 data and the αt^2 model with the α value of 0.02 kW/s^2 used. Ordinate is HRR (kW), and abscissa is time (s).

The alpha values used for these two models shown within Figure 117 and Figure 118 correlate with a “slow” growing fire [2019 NFPA 72, Reference (s), Annex B Equation B.2.3.2.3.2].

Although the time to burnout was estimated above at 22 minutes “the decay phase of the fire commences when about 70-80% of the design fire load has been consumed. The decay phase HRR exhibits a linear decrease with time” [Reference (h) Page 1273]. Combustion efficiency in flashover conditions for this hypothetical fire is estimated to be at 50%. This is based upon the following:

- Polystyrene burns with about 45% efficiency [Reference (h) Page 399].
- Well-ventilated stack of wood pallets burns with 63% efficiency [Reference (h) Page 399].

This compartment fire will be ventilation limited in flashover conditions and is composed of mostly Class IV commodity materials including plastics and paper, so a combustion efficiency (ξ) of 50% is reasonable. The decay phase from a flashover fire typically occurs when 70-80% of the combustibles have been consumed [Reference (h) Page 1,273]. For this analysis, it is estimated that this decay phase will commence when 75% of the design fire load has been consumed, assuming this to be an average fire scenario.

Both αt^2 models are used to bound the likely fire growth. Due to the long rise time using the slow burning αt^2 fire models, estimating time to burnout will also use an energy approach as well as the 22 minutes estimated above. The following is an estimate for the total amount of energy the combustibles in this compartment contain:

$Q = 570\ MJ/m^2 * 3\ m \times 4.5\ m$ [Total energy]
$Q = 7{,}695\ MJ$

Energy (Q) for the pre-flashover conditions is estimated by integrating αt^2 from Figure 117 from the start of the fire to flashover HRR as estimated from the Thomas model. This decay phase analysis only considers the slower burning bounding model, as that is the model that is going to burn the longest.

$Q = 1/3\ \alpha\ (720)^3$
$Q = 1/3 * 0.003 * 720^3$
$Q = 373\ MJ$

The total amount of energy available for combustion is as follows:

$Q_{Available} = Q * \xi = 7{,}695\ MJ * 50\%$
$Q_{Available} = 3{,}850\ MJ$

The decay phase of this compartment fire starts at approximately 75% of 3,850 MJ for the slower burning fire. Figure 119 has been created by combining the various models in the above discussion.

Using this model, the estimated maximum duration for the fire is just under 31 minutes in comparison to the 22 minutes previously estimated due to the long fire decay process.

The office compartment is suppressed; however, impairments due to pipe damage, power outages and other potential problems do occur. The model shown in Figure 119 represents fire conditions when suppression is not available that allows full growth through flashover and into the decay phase in the absence of manual firefighting operations. This worst-case situation will result in substantial smoke and toxic gases, including CO, filling the exit access stairway, and rising to the second floor.

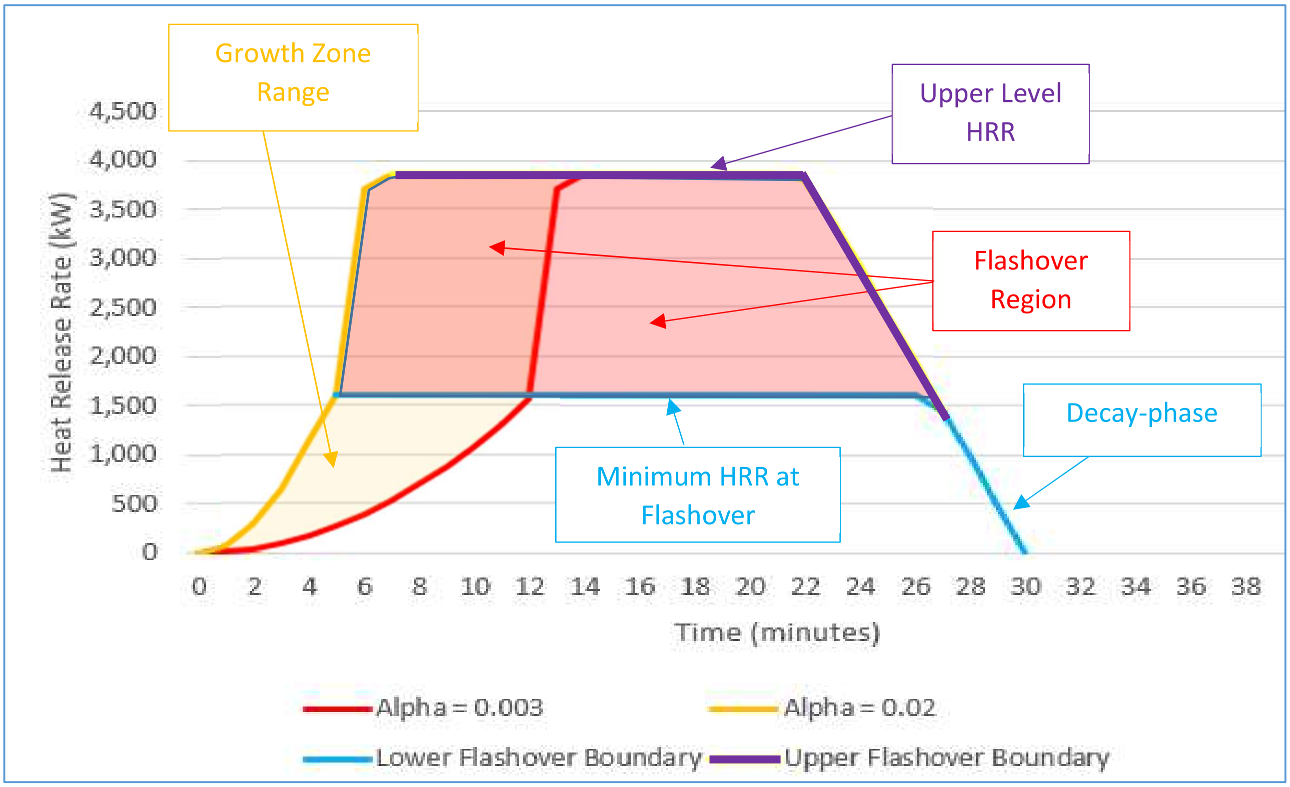


Figure 119: Theoretical worst-case fire model for office location.

Administrative policies prohibit personnel from sleeping, so it is expected that the pre-flashover time will provide ample time to sense and react to a fire condition in this compartment. The large area of the second floor provides reasonable confidence that untenable conditions will not be reached until flashover occurs, so this theoretical fire scenario is likely not to impact safe egress of personnel.

The smoke odor will trigger the occupants to investigate where the smell is coming from. Local policies require emergency actions to be taken if smoke is seen. An example from 1975 in the World Trade Center involved a trash can fire that resulted in the smoke smell affecting floors several stories above the fire location [Reference (k) 4-4]. This small example fire started at 9:04 am and resulted in personnel assembling within a common area on floors above this fire location. A public address announcement came in only six minutes later (9:10 am) explaining the situation to personnel and that there was no emergency. This example demonstrates that the smoke smell can be noticed quickly even at a substantial distance away. Personnel will have ample time to notice the smoke smell, react, and egress safely before tenability is impacted on the second floor, which is the primary area of concern regarding safe egress impacts due to this fire scenario.

The purpose of creating the HRR profile shown in Figure 119 was to contrast a theoretical worst-case fire with the fire profile shown in Figure 114. The Figure 114 HRR is taken from measurements from actual fires, so it appropriately represents the kind of expected fire performance in this office space. Using these two HRR profiles bounds the conditions this office could experience within a fire situation.

FDS is used to model the composite workstation fire HRR curve shown in Figure 114. A 2% soot production rate is defined within the FDS modeling. The NFRL room fire data in the Reference (q) Database supports a 2% soot production range for this design fire. These room tests performed by NFRL relied on a higher ventilation factor ($A_oH_o^{1/2}$) for their tests than this compartment fire; however, the soot yield is within the range applied for this fire as shown below.

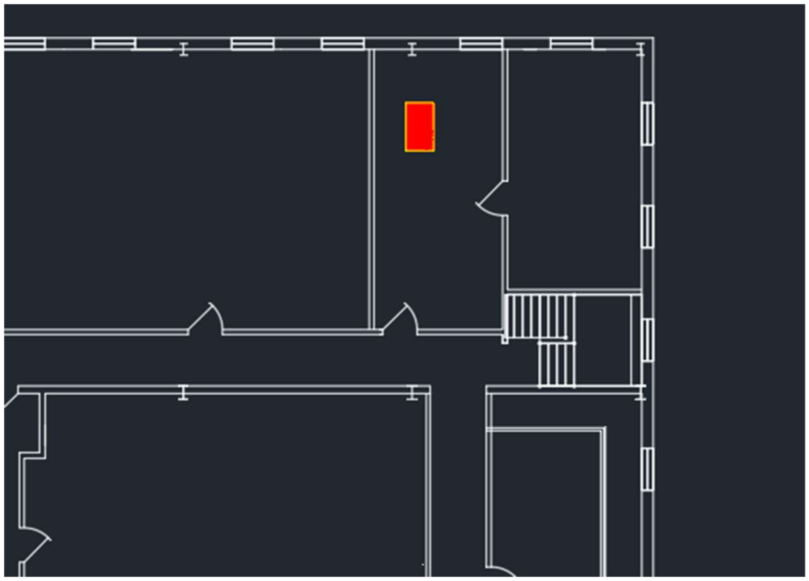


Figure 120: A simplified plan view drawing of where this fire is modeled.

Table 15: NFRL data for soot yield for different compartments.

NIST/NFRL Test Data for Rooms Similar to this Compartment			
	Soot Yield	Flashover (min)	PHRR (kW)
Test 1	2.44%	6.9	9,175
Test 2	1.12%	20.92	8,422
Test 3	2.32%	6.05	9,639

Figure 121 demonstrates the smoke layer thickness on the first and second floors. By observation, FDS estimates a thicker but less dense layer of smoke in the second-floor corridor. This is due to mixing and air entrainment as the smoke rises from the first floor into the second floor. The smoke layer interface remains above six feet on the first floor for over 5 minutes. The smoke level in the second-floor corridor reaches six feet above the floor in about 100 seconds and then drops down to about 3.5-feet above the floor for several additional minutes.

The HRR model used for FDS shown in the images below was from Figure 114. This FDS model relied on the actual measured composite workstation HRR rather than the theoretical worst-case. The FDS model does not show flashover occurring even at the PHRR of 1.6 MW, which was the Thomas model predicted minimum HRR for flashover. The theoretical model shown in Figure 119 is significantly hotter than the actual measured composite workstation fire. Fire spread could occur within this compartment resulting in flashover, but likely not before suppression is activated.

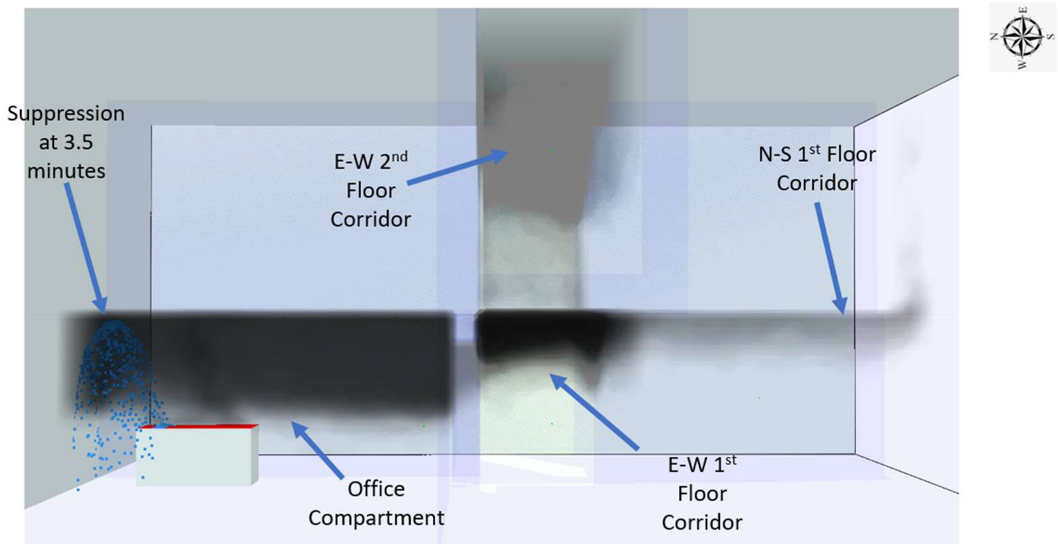


Figure 121: FDS results for the compartment fire as viewed from the west.

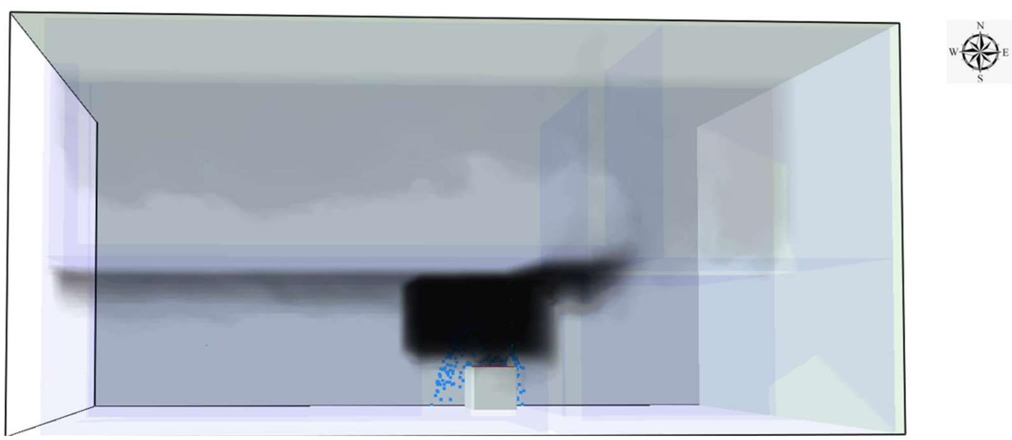


Figure 122: FDS results for the compartment fire as viewed from the south.

The areas of concern on the second floor involve cubicle office space. These locations have multiple exits that can be reached within a minute. Although the smoke layer interface height is only about 3.5-feet above the floor, the density of the smoke is low. As previously calculated, the occupants have at least one minute of being immersed in smoke prior to being incapacitated, so this area is not concerning from a safe egress perspective. If a more aggressive fire occurred such as shown in Figure 114, flashover conditions will be reached in the absence of suppression. FDS was also used to determine smoke performance with higher HRR values over a longer period. There was little change in the smoke layer heights of either the first or second floors during the period required for safe egress simply because of the large open-air volumes in the office spaces where these corridors lead to. It is reasonable to assume that occupants can safely egress with the fire profile shown in Figure 114 because of the short distances that need to be traveled in the corridors to reach exits.

Additional analysis will be performed using the HRR profiles evaluated in this section. These subsequent analyses will be performed to calculate the potential for fire spread and for sprinkler activation.

MOE Conclusion

This analysis relied both on a prescriptive and performance-based review of the ACME Building and proved using standard and accepted practices that this building is safe for personnel. This section of the analysis shows that the ACME Building is compliant with the means of egress code requirements as found in Chapter 10 of Reference (b) except for violations that are currently being repaired. This analysis also demonstrated that the worst-case locations remain in tenable conditions for a design basis fire to allow all occupants to safely egress. Although this is an old and large structure, its design is sufficiently safe for continued use.

SUPPRESSION SYSTEM EVALUATION

This section performs a review of the ACME Building sprinkler system to determine if the available water flow is sufficient for the system needs as defined within the 2019 NFPA 13, Standard for the Installation of Sprinkler Systems, Reference (t). This analysis does not characterize the entire sprinkler and water supply systems for this building but examines bounding systems that prove that the ACME Building will be effectively protected during a fire. Some assumptions and estimates were made (e.g. measurements) but a best-effort was given to ensure these were conservative.

the ACME Building was not sprinklered at the time of the initial 1959 construction but was retrofitted with an automatic sprinkler system starting in 1972. Each addition since 1972 has included an NFPA 13 compliant sprinkler system. A sprinkler system was installed in the hot cell processing area during a major reconstruction project completed in 1998. Seismic restraint is not implemented in a uniform manner on all sprinkler systems. Transverse and longitudinal bracing is not provided for every system. Where provided, not all locations have been adequately braced. One exception is the hot cell system that appears to be adequately braced. With a few exceptions, beam clamp type hangers do not have restraining straps.

The hot cell processing area and decontamination cell have a double-pre-action suppression system, but these areas have very low combustible loading. The remaining systems are water-filled standard suppression systems.

Nine automatic sprinkler system FDCs are installed around the perimeter of this building serving the 9 main risers. Riser 7 provides water to the double-pre-action systems serving the hot cells. Riser 1 supports a portion of this building with a standard automatic suppression system, but also branches off to supply water to a separate riser (Riser 10) that provides water to the decontamination cell (MC). The automatic suppression systems within the ACME Building are all NFPA 13 based suppression systems.

The original 1972 sprinkler system installation was a pipe schedule system. It appears that more recent systems have been hydraulically calculated based upon observed pipe sizes. The hydraulic nameplates at the respective risers and the internal records from the respective installations do not have adequate information for all the systems. To overcome this weakness, an analysis was conducted by Nexus Technical Service Corporation in 2011 that included the production of as-built drawings. This information has never been used to update the legacy hydraulic information tags at the respective risers but is available for review by the Fire Protection Engineering organization. It is recommended that the hydraulic tags be updated to reflect the current information as required by Reference (t).

This Nexus review did identify potential problems with the sprinkler systems, but the process of reviewing their conclusions in comparison to the actual the ACME Building systems as part of this analysis resulted in the reasonable assumption that any issues they identified were based on conservative measurements and assumptions that relied on lower flows and pressures to the Base Of the Riser (BOR) than what the ACME Building can actually provide. Recent flow measurements have demonstrated a much higher available flow and pressure than the assumptions provided to Nexus during their analysis. A more thorough review of the Nexus conclusions is recommended to be performed by the Cognizant System Engineer (CSE) over the suppression systems to compare the actual water delivery that is available to the BOR in comparison to the assumptions used by Nexus.

Identification, Location and Sizes of the Suppression Systems

The nine primary automatic sprinkler system risers are described as follows based upon the information from the hydraulic nameplates at each riser with the supplemental information from Nexus provided where applicable. All the above ground systems are Schedule 40 steel piping. Unless otherwise specified, the risers are eight inches, and the lead-in piping is eight inches in diameter and is assumed to be Schedule 40. The sprinkler's head heights are estimated by inspection and from existing drawings. There is approximately 0.433 PSI per foot of elevation due to the weight of water. Any reliance on the pressure estimates used in this document should factor in a few feet of tolerance for sprinkler head height and allow a margin of a couple PSI of additional pressure to ensure the results are reliable.

1) Riser 1 serves a high bay with sprinkler heads at an estimated height of 55'-60' Above the Base Of the Riser (ABOR) and also provides water to Riser 10:
    a. Density Design Area: 0.15 GPM/ft^2 over 1,586 ft^2.
    b. Hose Stream Allowance: 500 GPM.
    c. System Demand: 303.0 GPM at 58.5 Pounds per Square Inch (PSI) at the riser.
    d. Occupancy classification: Ordinary Hazard (OH) 1.
    e. Supplemental information:
        i. 379 sprinkler heads over 35,900 ft^2.
        ii. 165° Fahrenheit (F) Standard Response (SR) K-5.6 heads.
        iii. The feed-main is 8".
        iv. The cross-main ranges from 2" to 6".
        v. The branch-lines range from 1" to 1.25".

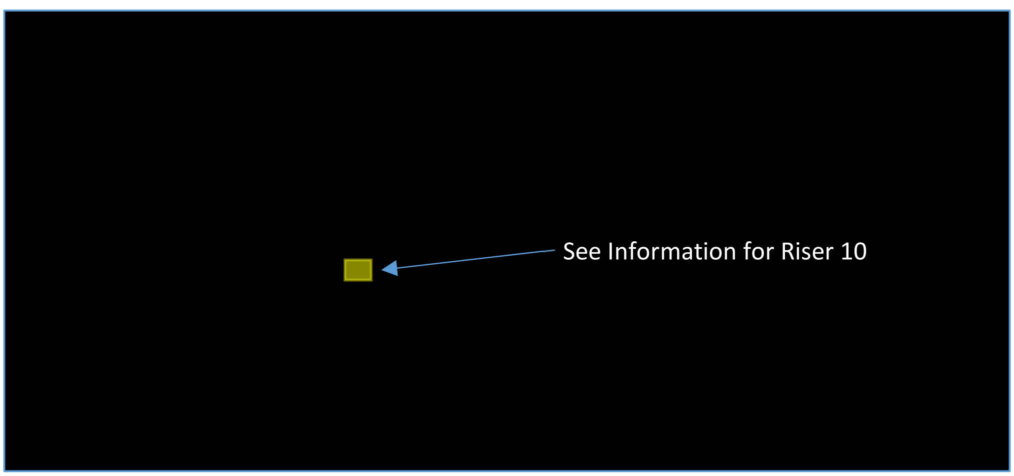


Figure 123: System coverage for water supplied to Riser 1.

Figure 124: Representative Fire Department Connection for Riser 1.

2) Riser 2 serves a high bay with sprinkler heads at approximately 55’-60’ ABOR:
    a. Density Design Area: 0.15 GPM/ft^2 over 1,562 ft^2.
    b. Hose stream allowance: None specified.
    c. System Demand: 298.3 GPM at 56.3 PSI at the riser.
    d. Occupancy Classification: OH 1.
    e. Supplemental information not on tags:
        i. 412 sprinkler heads over 41,500 ft^2.
        ii. 165° F SR K-5.6 heads.
        iii. The feed-main is 8”.
        iv. The cross-main ranges in size from 2” to 6”.
        v. The branch-lines range in size from 1” to 1.25”.

[redacted]

Figure 125: System coverage for water supplied to Riser 2.

3) Riser 3 serves two floors with an office area and an industrial area with mezzanines having a maximum sprinkler height of approximately 54’ ABOR:
    a. No information on riser nameplate.
    b. Supplemental information not on tags:
        i. 823 sprinkler heads over 64,600 ft^2

            *The 2016 NFPA 13, Reference (u), specifies 52,000 ft^2 total area of coverage where floors are not separated by fire rated construction. The 1969 NFPA 13, Reference (v), was likely used for this design. This specifies the same requirements, but also limits heads to 400 from an 8” riser and the 52,000 ft^2 would be limited to hydraulic calculations. The 52,000 ft^2 is based upon 400 heads * 130 ft^2/head. It is assumed that this installation took credit for the 1^{st} floor ceiling over some of the industrial area to meet the necessary fire rating that creates two separate fire areas between the first-floor industrial area and the second-floor business area. There is no documentation regarding this fire rated separation, but the installation is assumed to be code compliant.*

        ii. Mix of 165° F SR and 155° F Quick Response (QR) K-5.6 heads.
        iii. The feed-main is 8”.
        iv. The cross-mains range in size from 1.25” to 6”.
        v. The branch-lines range in size from 1” to 1.25”.

Figure 126: Representative FDC for Riser 3 on the north side of the ACME Building.

[redacted]

Figure 127: System coverage for water supplied to Riser 3.

Figure 128: Riser for System 3.

4) Riser 4 serves industrial and office areas with sprinklers at approximately 8’ and a high bay with sprinklers at approximately 52’-60’ ABOR:
    a. No information on nameplate.
    b. Supplemental information not on tags:
        i. 523 sprinkler heads over 41,500 ft^2.
        ii. Mix of 165° F SR and 155° F QR K-5.6 heads.
        iii. The feed-mains range in size from 4” to 6”.
        iv. The cross-mains range in size from 1.25” to 4”.
        v. The branch-lines range in size from 1” to 3”.

[redacted]

Figure 129: System coverage for water supplied to Riser 4.

Figure 130: The FDC does not currently identify what system it supports.

5) Riser 5 serves a metal fabrication shop with sprinklers approximately 40' ABOR:
    a. Density Design Area: 0.21 GPM over 1,500 ft^2.
    b. Hose Stream Allowance: None specified.
    c. System Demand: None specified.
    d. Occupancy Classification: OH 1.
    e. Supplemental information not on tags:
        i. 63 sprinkler heads over 6,000 ft^2.
        ii. 165° F SR K-5.6 heads.
        iii. The lead-in is 6".
        iv. The riser is 4".
        v. The feed-main is 4".
        vi. The cross-main is 3".
        vii. The branch-lines are 1"-1.5".

Figure 131: System coverage for water supplied to Riser 5.

6) Riser 6 serves a plastic drape fabrication area with sprinklers approximately 10’ ABOR:
    a. No information on riser nameplate.
    b. Supplemental information not on tags:
        i. 122 sprinkler heads over 9,300 ft^2.
        ii. 165° F SR K-5.6 heads.
        iii. The lead-in is 6”.
        iv. The riser is 6”.
        v. The feed-main is 6”.
        vi. The cross-mains range from 2.5” – 3”.
        vii. The branch-lines range from 1” – 1.5”.

Figure 132: System coverage for water supplied to Riser 6.

7) Riser 7 serves the hot cells with sprinklers at approximately 12.5’ ABOR:
    a. Density Design Area: 0.15 GPM (no area specified).
    b. Hose Stream Allowance: None specified.
    c. System Demand: 143.1 GPM at 64.0 PSI at the riser.
    d. Occupancy Classification: OH 2.
    e. Sprinkler Head Data: None.
    f. Supplemental information not on tags:
        i. 38 sprinkler heads over 2,400 ft^2.
        ii. 165° F SR K-5.6 heads, spray nozzles and side-walls.
        iii. Riser 7 is fed from Riser 3.
        iv. The riser diameter is 4”.
        v. The feed-main is 4”.
        vi. The cross-mains are 2”.
        vii. The branch-lines range from 1”-1.5”.

[redacted]

Figure 133: System coverage for water supplied to Riser 7.

8) Riser 8 serves a high-bay area with sprinklers at approximately 90’ ABOR:
   a. No Information on nameplate.
   b. Supplemental information not on tags:
      i. 315 sprinkler heads over 21,300 ft^2.
      ii. 165° F SR K-5.6 heads.
      iii. The riser is 6”.
      iv. The feed-main is 4”.
      v. The cross-mains are 1.5”-3”.
      vi. The branch-lines are 1”-1.25”.

Figure 134: System coverage for water supplied to Riser 8.

9) Riser 9 serves a storage area with a low-piled storage configuration with Class III commodities. This area has a sloped ceiling with heads ranging from approximately 10’ to 42’ in height:
   a. No Information on nameplate
   b. Supplemental information not on tags:
      i. 153 sprinkler heads over 16,000 ft^2.
      ii. 7-165° F, 146-212° F, all SR K-5.6.
      iii. The riser is 4”.
      iv. The feed-main is 4”.
      v. The cross-mains are 1.5” – 2.5”.
      vi. The branch-lines are 1.25”.

[redacted]

Figure 135: System coverage for water supplied to Riser 9.

10) Riser 10 serves the Decontamination Shop and is supplied by Riser 1. The area of coverage is the subset for system 10 shown in Figure 123 for Riser 1:
    a. Density:
        i. Compartment at 0.21 GPM for 5 sprinklers (640 ft^2).
        ii. Compartment at 0.21 GPM for 7 sprinklers (448 ft^2).
    b. Hose Stream Allowance: 500 GPM.
    c. System Demand:
        i. 649 GPM at 53.3 PSI at the riser.
        ii. 648.7 GPM at 38.1 PSI at the riser.
    d. Designated Occupancy Class: OH 1.
    e. Sprinkler Head Data:
        i. 5-165° F K-5.6.
        ii. 7-165° F K-5.6.
        iii. 3-162° F K-5.6.
    f. This 3" riser is fed from Riser 1.
    g. The feed-main is 3".
    h. The cross-main is 3".
    i. The branch-lines are 1" – 2".

Characterization of the Fire Suppression Water Supply

The underground water system that attaches to the Point Of Connection (POC) from each riser is made up of 8", 10", and 12" Schedule 40 underground piping in a looped configuration. There is minimal elevation difference around the perimeter of this building complex. The water system supply value has been specified for the POC for all nine riser connections through flow testing. The information from this flow test was used to derive the following water supply:

- Static pressure: 157 PSI
- Residual pressure: 60 PSI at 2,100 GPM

The above data was taken from a 2017 flow test and was likely biased due to potentially incorrect calculations. In 2021, additional flow tests were performed that showed 2,093 GPM with a residual pressure of 91 PSI and a static no-flow pressure of 141 PSI near the location recorded above for 2017. Although this more recent flow has better results, the 2017 data is used for this analysis to add additional conservatism to the results.

An Aurora horizontal centrifugal fire pump in the south pump house (PNNRA-635) is the weakest of the two fire pumps that support the ACME Building. Its rating is 125 PSI at 2,000 GPM. The N1.85 log graph in Figure 136 shows this fire pump's theoretically estimated performance curve. A churn pressure of 1.2 times the rated pressure is applied (150 PSI) on this graph as is expected for a horizontal centrifugal fire pump. 3,000 GPM at a pressure of 81 PSI is also assumed per that fire pump's standard performance curve. These values are the expected values per the NFPA defined pump curve for a certified fire pump.

The estimated water supply as measured from the 2017 flow is superimposed in Figure 136 to contrast the measured flow with the expected pump performance. It can be observed from this figure that the slope for the water delivery estimate indicates far more frictional losses than more recent testing has indicated. This is why it can be concluded that the 2017 data is extremely conservative and provides a worst-case baseline to contrast suppression performance.

The underground looped system is oversized and is known to be in good condition, so it will not produce enough friction to cause the pressure drop that is shown in Figure 136 for the derived water supply shown as the “FH-659-N flow test.” The good condition of the looped underground system was established by simultaneously running multiple fire pumps and by opening multiple hydrants and measuring the flows and residual pressures as part of a 2017 effort to characterize the PNNRA underground piping. That analysis concluded that PNNRA’s underground system was in good health.

There are two deep wells that provide water to storage tanks for the fire water. These deep wells can provide water at 2,000 GPM. Water is pumped from one of the deep wells into the 100,000-gallon water tank on the south side of the campus (S5G water storage tank, PNNRA-715). This tank provides water to the fire pump at this location. There is a second fire pump that supplies water from a 50,000-gallon water tank adjacent to the ACME Building (S1W Raw Water Tank, PNNRA-726). A 150,000-gallon water tank is also immediately south of the ACME Building that has a separate fire pump (PNNRA-695). The water lines connecting these three pumps and tanks are connected to each other, so water is readily available to meet system needs. There is also a continuously running pressure maintenance pump located adjacent to the 100,000-gallon S5G tank on the south side of the campus (adjacent to PNNRA-635). It is used as the pressure maintenance pump and maintains pressure at a constant rate of just over 150 PSI for the entire system.

Detailed Analysis of System 3

This section reviews the performance of System 3, which is fed by Riser 3. This system is selected for more scrutiny as it has the longest equivalent distance for water delivery when factoring in the pipe elbows and other components. It was also designed and installed with the pipe-schedule method. Because of these factors, System 3 is a bounding design. If System 3 is adequate, it is assumed the remainder of the ACME Building sprinkler systems are acceptable.

Riser 3 has an 8” riser that is fed by an 8” underground lead-in that extends north from the riser by approximately 70-feet to the POC with the 10” underground fire water loop. This lead-in also supplies the water for Riser 7.

The design criteria for the Group F-1 area that System 3 protects is as follows based upon the minimum requirements from Reference (u):

- OH1 (Reference (u) Section 5.3.1.1).
- 0.15 GPM/ft^2 for a design area of 1,500 ft^2 (Reference (u) Figure 11.2.3.1.1).
- Hose stream allowance (HSA) of 250 GPM (Reference (u) Table 11.2.3.1.2).

The following figures and tables characterize the System 3 sprinkler system and provide the necessary data to perform a hydraulic analysis on this system.

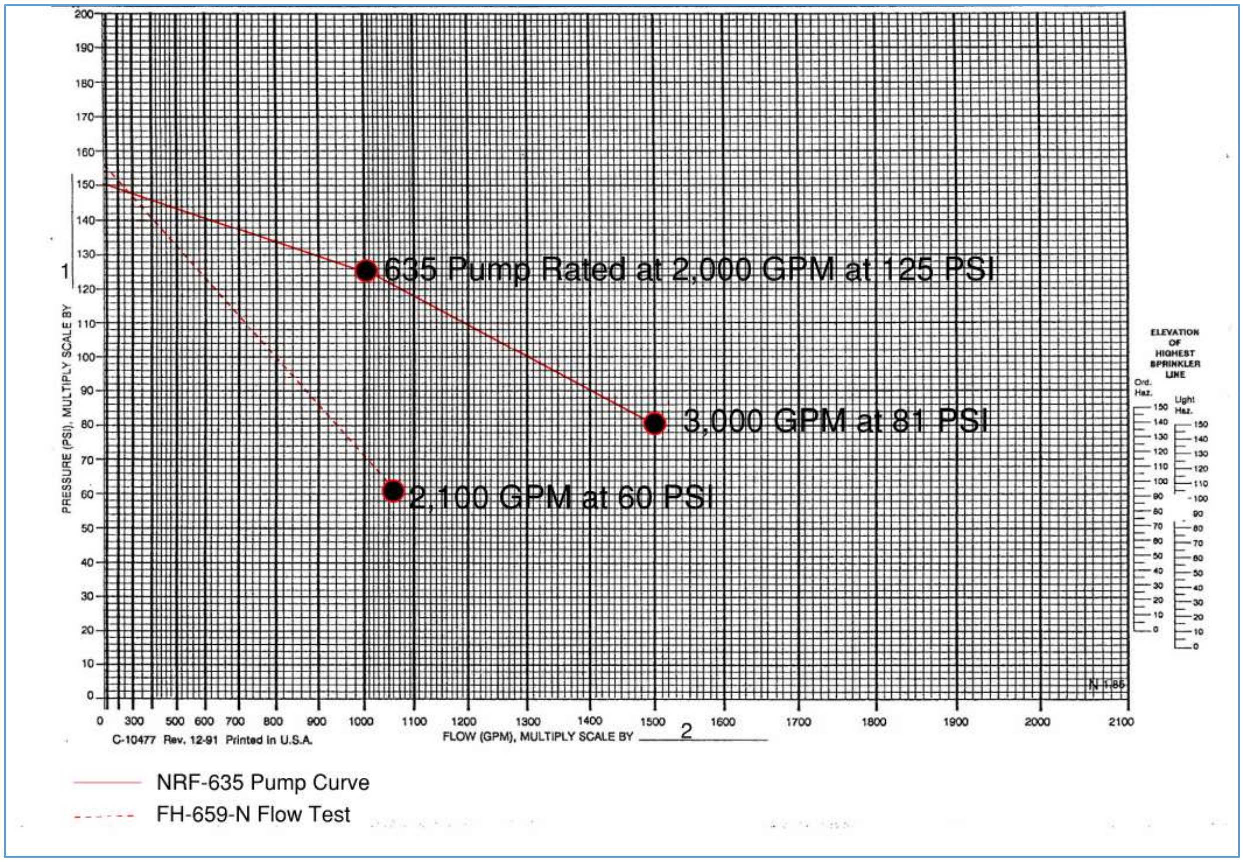


Figure 136: Logarithmic pump curve graph from a fire hydrant flow test in 2017.

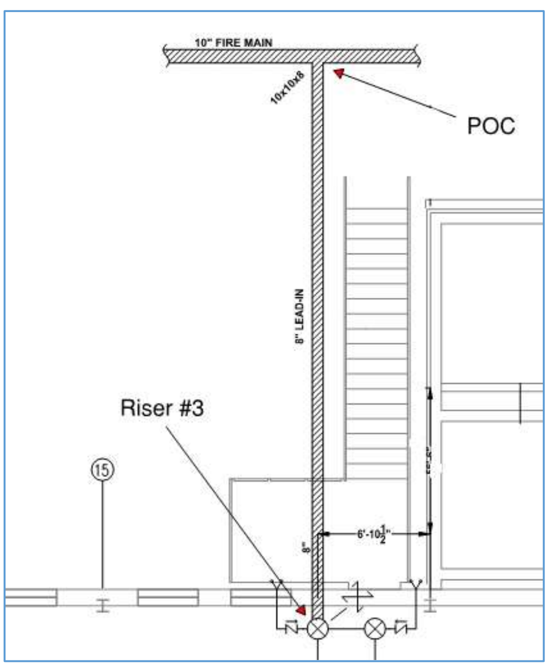


Figure 137: POC and lead-in for riser 3.

Hydraulic Calculations for System #3

The most remote area for System 3 is identified in Figure 138. The table below shows the type and lengths of pipe from the POC to the last head following the path defined in Figure 138. Equivalent lengths came from the Reference (u) Table 23.4.3.1.1. The “ID” numbers shown below are the piping changes and analysis points in sequence from the POC to the last sprinkler head for this analysis. Not all these ID numbers are shown in Figure 138, but are included in this table so a complete inventory of piping and elevation changes can be documented.

Table 16: Pipe sizes for water delivery to the most remote location for System #3.

ID	Size	Distance	ID	Size	Distance
1	8” Lead-in	70’-0”	36	End of Branch Line (BL) 6	
2	8” Elbow	18’	37	2.5” Pipe	10’
3	8” Clapper	45’	38	BL5	
4	8” Butterfly Valve	12’	39	1.5” T	8’
5	Elevation	Pe = 7’-6”	40	1.5” Pipe	4’
6	8” Pipe	22’-11”	41	Elevation	4’
7	8” Elbow	18’	42	1” T	5’ (Head)
8	8” Pipe	25’-11”	43	1” Pipe	9’-3” (Head)
9	8” T	35’	44	1” Pipe	9’-3” (Head)
10	8” Pipe	6’-10”	45	End of BL5	
11	6” Pipe	2’-1”	46	2” Pipe	9’-10”
12	6” Elbow	14’	47	BL4	
13	6” Pipe	30’8”	48	1” T	5’
14	Elevation	Pe=30’-8”	49	1” Pipe	4’
15	6” Elbow	14’	50	Elevation	4’
16	6” Pipe:	12’-9”	51	1” Elbow	2’
17	6” Elbow	14’	52	1” Pipe	3’-2” (Head)
18	6” Pipe	27’-2”	53	1” Pipe	12’-10” (Head)
19	5” T	25’	54	End of BL4	
20	5” Pipe:	22’-8”	55	2” Pipe	10’
21	4” T	20’	56	BL3	
22	4” Pipe	51’-7”	57	1” T	5’
23	3” Pipe	5’	58	1” Pipe	4’
24	3” Elbow	7’	59	Elevation	4’
25	3” Pipe	2’-8”	60	1” Elbow	2’
26	3” Elbow	7’	61	1” Pipe	3’-2” (Head)
27	3” pipe	26’	62	1” Pipe	12’-10” (Head)
28	2.5” Pipe	21’-7”	63	End of BL3	
29	BL6		64	1.5” Pipe	10’
30	1” T	5’	65	BL2	
31	1” Pipe	4’	66	1” T	5’
32	Elevation	4’	67	1” Pipe	8”
33	1” Elbow	2’	68	Elevation	8”
34	1” Pipe	3’-2” (Head)	69	1” Elbow	2’
35	1” Pipe	12’-10” (Head)	70	1” Pipe	3’-2” (Head)
			71	1” Pipe	12’-10” (Head)
			72	End of BL2	
			73	1.5” Pipe	10’
			74	BL1	
			75	1” T	5’
			76	1” Pipe	8”
			77	Elevation	8”
			78	1” Elbow	2’
			79	1” Pipe	3’-2” (Head)
			80	1” Pipe	12’-10” (Head)

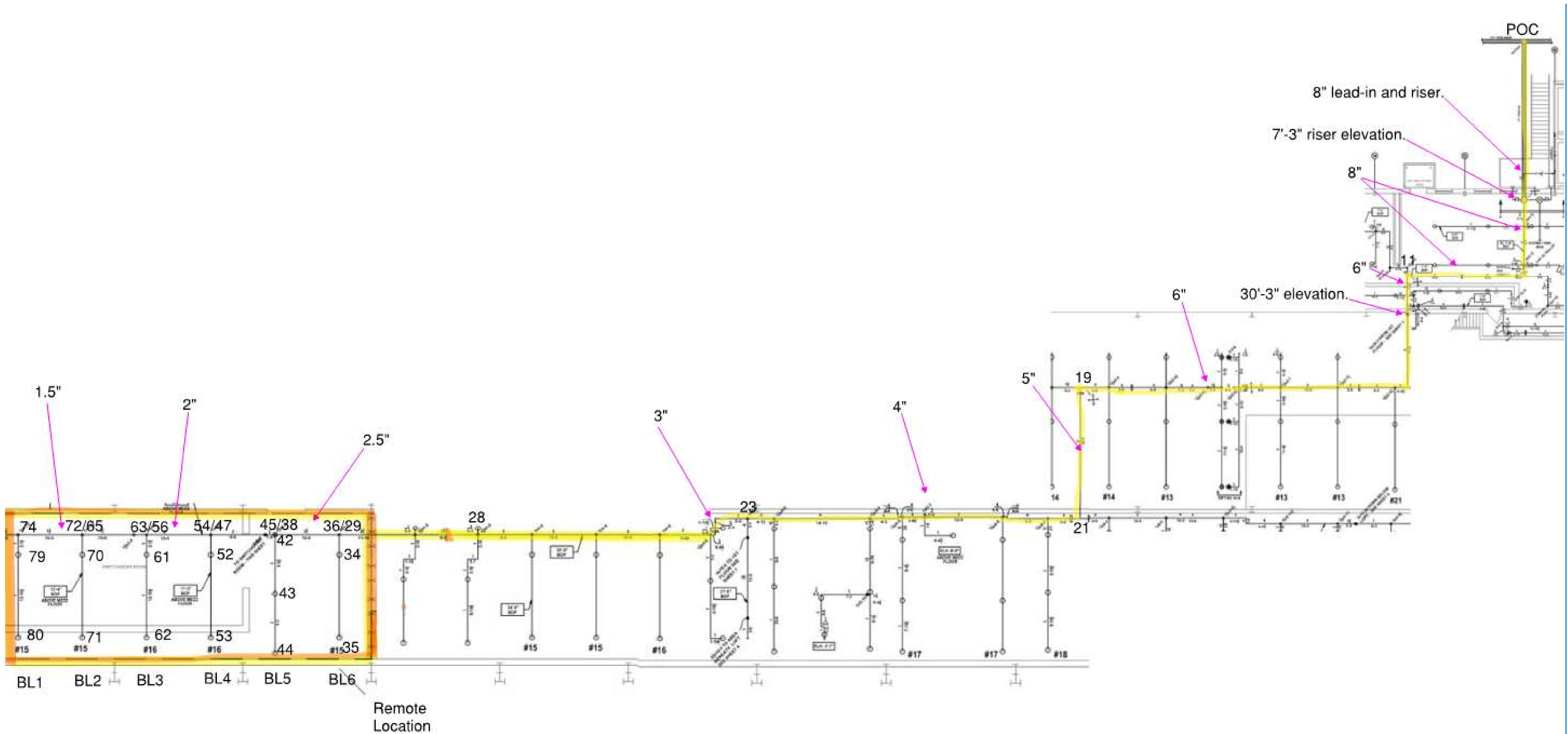


Figure 138: System 3 showing the most remote location for analysis, the path of water to that remote location, the respective diameter of the pipe and the applicable ID items as shown in Table 1.

System #3 uses Central (now TYCO) series 804a sprinkler heads having a K-factor of 5.6. The remote area for System #3 is identified by inspection as the location that is most challenging to deliver water to for the system as shown in Figure 138. The number of sprinklers to analyze is the required OH1 design area divided by the area of coverage for each as-built sprinkler which gives 13 sprinkler heads:

1,500 ft^2 / 116 ft^2 = 13 sprinklers

There is some variability in the as-built spacing for each sprinkler head, but the aggregate of the 13 sprinklers covers just over 1,500 square feet. Because of this difference in area per sprinkler head, the hydraulic calculations will conservatively start with a pressure required to distribute 0.15 GPM/ft^2 over 130 ft^2. That pressure is 12.1 PSI {$(0.15\ GPM/ft^2 * 130\ ft^2 / 5.6)^2$}. The below table shows the hydraulic calculations for the most remote area of System 3.

Table 17: Hydraulic Calculations for System #3.

Step	Nozzle Ident and Location		Flow in gpm		Pipe size	Pipe Fittings and Devices	Equivalent Length (ft)		Friction loss (psi/ft)		Pressure Summary		Normal Pressure			Notes
1	80	BL1	q		1		L	12.83			Pt	14.5	Pt		K	Q = 130 * 0.15; Q = 19.5 GPM
		79			1.049		F				Pe		Pv		5.6	P = (19.5 / 5.6)^2; P = 12.1 PSI (+2.4)
			Q	21.3			T	12.83	pf	0.147	Pf	1.9	Pn			Added 2.4 PSI due to BL3/4 elevation
2	79		q	22.7	1	1E-2	L	3.83			Pt	16.4	Pt			q = k * Pt^.5
		74			1.049	1T-5	F	7			Pe	0.3	Pv			Pe = 8/12' * 0.433
			Q	44.0			T	10.83	pf	0.559	Pf	6.1	Pn			
3	74		q		1.5		L	10			Pt	22.7	Pt		9.2	K for BL1 = Q/Pt^0.5 (and BL2)
		72			1.61		F				Pe		Pv			
			Q	44.0			T	10	pf	0.069	Pf	0.7	Pn			
4	72	BL2	q	44.7	1.5		L	10			Pt	23.4	Pt			q = k * Pt^.5
		63			1.61		F				Pe		Pv			
			Q	88.6			T	10	pf	0.254	Pf	2.5	Pn			
	Evaluation of K for BL3 (and BL4, BL6). This section just finds the applicable K value.															
A	62	BL3	q		1		L	12.83			Pt	12.1	Pt		K	Arbitrary value to find K for BL3 (4, 6)
		61			1.049		F				Pe		Pv			
			Q	19.5			T	12.83	pf	0.124	Pf	1.6	Pn			
B	61		q	20.7	1	1E-2	L	7.17			Pt	13.7	Pt			q = k * Pt^.5
		56			1.049	1T-5	F	7			Pe	1.7	Pv			Pe = 4' * 0.433
			Q	40.2			T	14.17	pf	0.473	Pf	6.7	Pn			
											Pt	22.1			8.6	K for BL3 = q/Pt^.5
	Resuming at 63 with the K-value defined above															
5	63	BL3	q	43.6	2		L	10			Pt	26.0	Pt		8.6	
		54			2.067		F				Pe		Pv			
			Q	132.2			T	10	pf	0.158	Pf	1.6	Pn			
6	54	BL4	q	48.4	2		L	9.833			Pt	27.5	Pt			q = k * Pt^.5
		45			2.067		F				Pe		Pv			
			Q	180.6			T	9.833	pf	0.281	Pf	2.8	Pn			
											Pt	30.3				
	Evaluation of K for BL5. This section just finds the applicable K value.															
A	44	BL5	q		1		L	9.25			Pt	12.1	Pt			Arbitrary value to find K for BL5
		43			1.049		F				Pe		Pv			q = k * Pt^.5
			Q	19.5			T	9.25	pf	0.124	Pf	1.1	Pn			
B	43		q	20.4	1	1T-5	L	9.25			Pt	13.2	Pt			
		42			1.049		F	5			Pe		Pv			
			Q	39.9			T	14.25	pf	0.466	Pf	6.6	Pn			
C	42		q	25.0	1.5	1T-8	L	4			Pt	19.9	Pt			
		38			1.61		F	8			Pe	1.7	Pv			
			Q	64.8			T	12	pf	0.142	Pf	1.7	Pn			Pe = 4' * 0.433
											Pt	23.3			13.4	

Continued: Table 17: Hydraulic Calculations for System #3.

Step	Nozzle Ident and Location		Flow in gpm		Pipe size	Pipe Fittings and Devices	Equivalent Length (ft)		Friction loss (psi/ft) (C=120)		Pressure Summary (PSI)		Normal Pressure		Notes
Resuming at 45 with the K-value defined above															
7	45	BL5	q	73.9	2.5		L	10			Pt	30.3	Pt		q=k*Pt^.5
		36			2.469		F				Pe		Pv		
			Q	254.6			T	10	pf	0.223	Pf	2.2	Pn		
8	36	BL6	q	48.8	2.5		L	21.58			Pt	32.5	Pt		
		28			2.469		F				Pe		Pv		
			Q	303.4			T	21.58	pf	0.308	Pf	6.6	Pn		
9	28		q		3	2E-14	L	33.67			Pt	39.2	Pt		
		23			3.068		F	14			Pe		Pv		
			Q	303.4			T	47.67	pf	0.107	Pf	5.1	Pn		
10	23		q		4	1T-20	L	51.58			Pt	44.3	Pt		
		21			4.026		F	20			Pe		Pv		
			Q	303.4			T	71.58	pf	0.028	Pf	2.0	Pn		
11	21		q		5	1T-25	L	22.67			Pt	46.3	Pt		
		19			5.047		F	25			Pe		Pv		
			Q	303.4			T	47.67	pf	0.009	Pf	0.5	Pn		
12	19		q		6	3E-42	L	72.67			Pt	46.8	Pt		
		11			6.065		F	42			Pe	13.3	Pv		Pe = 30'-8" * 0.433
			Q	303.4			T	114.67	pf	0.004	Pf	0.4	Pn		
13	10	POC	q		8	2E-36	L	125.7			Pt	60.5	Pt		
		1			7.981	1T-35	F	128			Pe	3.2	Pv		Pe=7'-6" * 0.433
			Q	**303.4**		1S-45, 1V-12	T	253.7	pf	0.001	Pf	0.3	Pn		
											Pt	**64.0**			

The hydraulic calculations show that the OH1 occupancy hazard classification for System 3 requires 303.4 GPM at 64 PSI at the POC, plus an additional 250 GPM for the HSA.

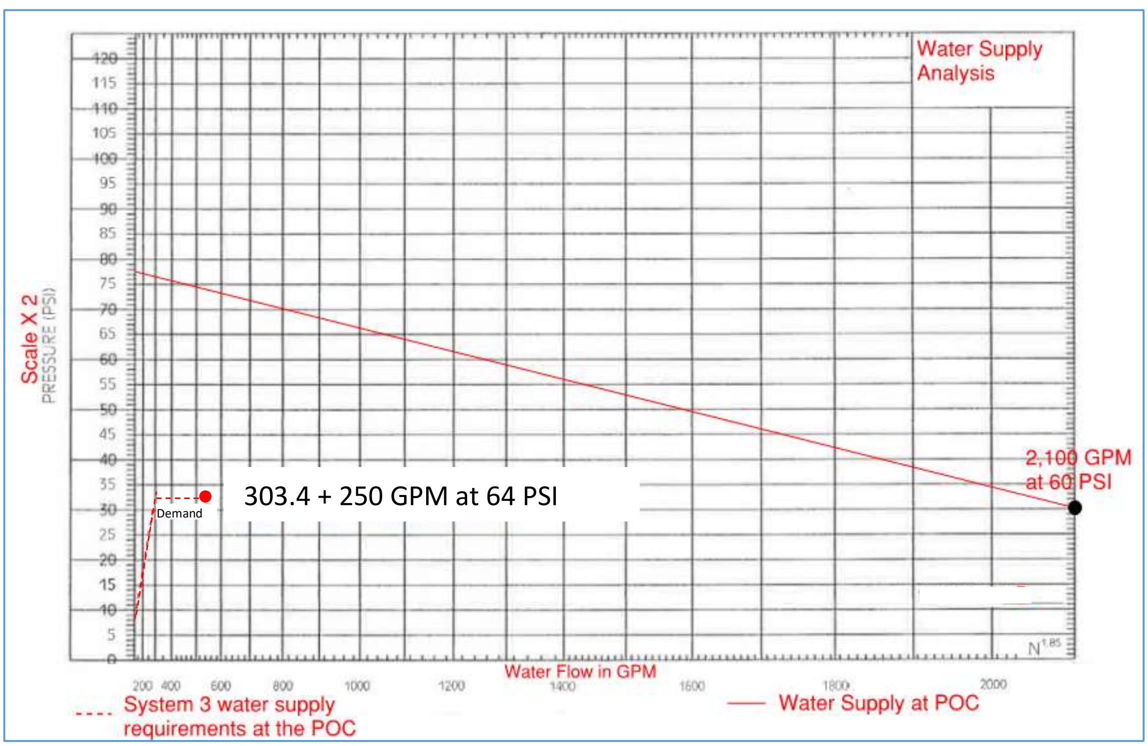


Figure 139: System requirements versus the water supply availability showing a wide safety margin for System 3.

Figure 139 shows that the required water flow and pressure, as required by Reference (u), at the POC for System 3 is significantly below the available water flow supplied by the underground loop. This provides ample margin for additional expansion and gives credibility that the pipe-schedule system installed in the 1970's will be adequate for our OH occupancy hazard classification. The local policies for the ACME Building rely on a 500 GPM hose stream allowance for new buildings instead of the Code required 250 GPM. Figure 139 shows that the additional 250 GPM is readily available.

System 3 is considered the worst-case system because of the pipe-schedule installation design and because of the water delivery distance from the POC. Other systems within this building complex have a higher elevation but cover a smaller area and have a shorter distance for water delivery. System 8 has a much higher elevation; however, this system was hydraulically designed and installed in the 2007 timeframe so is not suspect to be non-code compliant.

Inspection, Testing and Maintenance for System 3

IT&M frequencies are shown in Figure 140, which reflects the requirements from the 2017 NFPA 25, Reference (w). The IT&M in Figure 140 is broken up into different required periodicities. The quarterly checks are performed independently by a subcontractor. Other checks are performed by the ACME Building personnel.

Sprinkler Activation in the High Bay:

The DBF truck fire at the location shown in Figure 108 that used the HRR profiles shown in Figure 109 will not initiate suppression in all cases. Two different methods were used to calculate suppression activation time for the truck fire in the west high bay:

1) Detector Activation (DETACT) method.
2) FDS with sprinkler particles activated.

Figure 141 shows the DETACT results superimposed on the HRR profile for the truck fire. This image shows the expected sprinkler activation time and HRR range for the high bay area. The sprinklers will activate for the higher HRR in around 4.5 minutes after the start of the fire but will never activate for the lower 2-sedan HRR profile. The reason for this is that sprinkler heads act as heat detectors. The suppression heads in the high bay are rated at 165° F but require temperatures above this value for activation. The truck fire creates a buoyant smoke plume that rises, which entrains additional air adjacent to the smoke plume. This results in a cooling effect so that the ceiling jet of smoke at the 60-foot-high ceiling, which is created by this fire is not sufficiently hot to activate the sprinkler heads in most cases. Suppression systems within high bay or atrium locations are known to be ineffective at controlling fires. Factory Mutual does publish suppression standards for atrium ceilings that require much larger sprinkler heads that have earlier activation times (lower response time indices) than the K5.6 SR heads installed in the high bay locations within the ACME Building. Even the Factory Mutual data sheets for sprinkler installations lack reliable activation in many cases. They do have known limitations for open atrium environments like this high bay structure.

FDS was also used to calculate the suppression activation time. Figure 142 shows a Smokeview rendering of the FDS results that illustrates the fire and the appearance of the sprinkler activation. FDS calculated a sprinkler activation time that is approximately the same as the DETACT method for the upper HRR. FDS also proved that suppression activation will not ever occur for the lower HRR profile as was validated through the DETACT method.

Item	Frequency	Reference
Inspection		
Gauges (dry, preaction, and deluge systems)	Weekly/quarterly	5.2.4.2, 5.2.4.3, 5.2.4.4
Control valves		Table 13.1.1.2
Waterflow alarm devices	Quarterly	5.2.5
Valve supervisory signal devices	Quarterly	5.2.5
Supervisory signal devices (except valve supervisory switches)	Quarterly	5.2.5
Gauges (wet pipe systems)	Quarterly	5.2.4.1
Hydraulic nameplate	Quarterly	5.2.6
Buildings	Annually (prior to freezing weather)	4.1.1.1
Hanger/seismic bracing	Annually	5.2.3
Pipe and fittings	Annually	5.2.2
Sprinklers	Annually	5.2.1
Spare sprinklers	Annually	5.2.1.4
Information sign	Annually	5.2.8
Fire department connections		Table 13.1.1.2
Valves (all types)		Table 13.1.1.2
Obstruction, internal inspection of piping	5 years	14.2
Heat trace	Per manufacturer's requirements	5.2.7
Test		
Waterflow alarm devices		
Mechanical devices	Quarterly	5.3.3.1
Vane and pressure switch–type devices	Semiannually	5.3.3.2
Valve supervisory signal devices		Table 13.1.1.2
Supervisory signal devices (except valve supervisory switches)		Table 13.1.1.2
Main drain		Table 13.1.1.2
Antifreeze solution	Annually	5.3.4
Gauges	5 years	5.3.2
Sprinklers (extra-high or greater temperature solder type)	5 years	5.3.1.1.1.4
Sprinklers (fast-response)	At 20 years and every 10 years thereafter	5.3.1.1.1.3
Sprinklers	At 50 years and every 10 years thereafter	5.3.1.1.1
Sprinklers	At 75 years and every 5 years thereafter	5.3.1.1.1.5
Sprinklers (dry)	At 10 years and every 10 years thereafter	5.3.1.1.1.6
Sprinklers (in harsh environments)	5 years	5.3.1.1.2
Valves (all types)		Table 13.1.1.2
Valve status test		13.3.1.2.1
Maintenance		
Valves (all types)		Table 13.1.1.2
Low-point drains (dry pipe system)		13.4.4.3.2
Sprinklers and automatic spray nozzles protecting commercial cooking equipment and ventilation systems	Annually	5.4.1.9

Figure 140: Suppression IT&M frequency as specified in Reference (w).

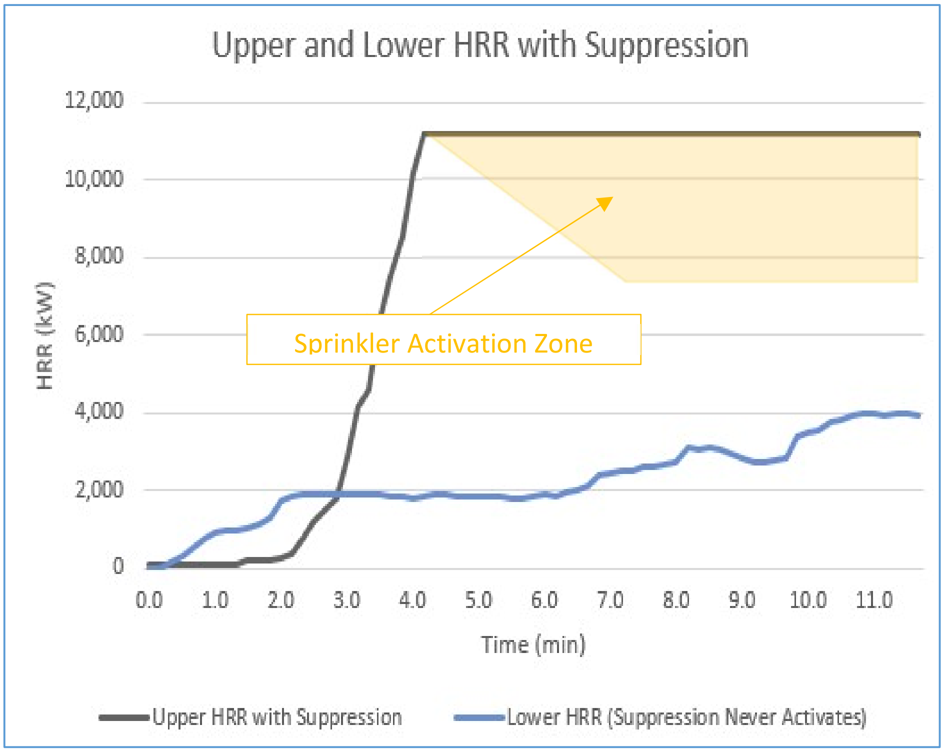


Figure 141: Sprinkler activation range with the two HRR profiles for the truck fire.

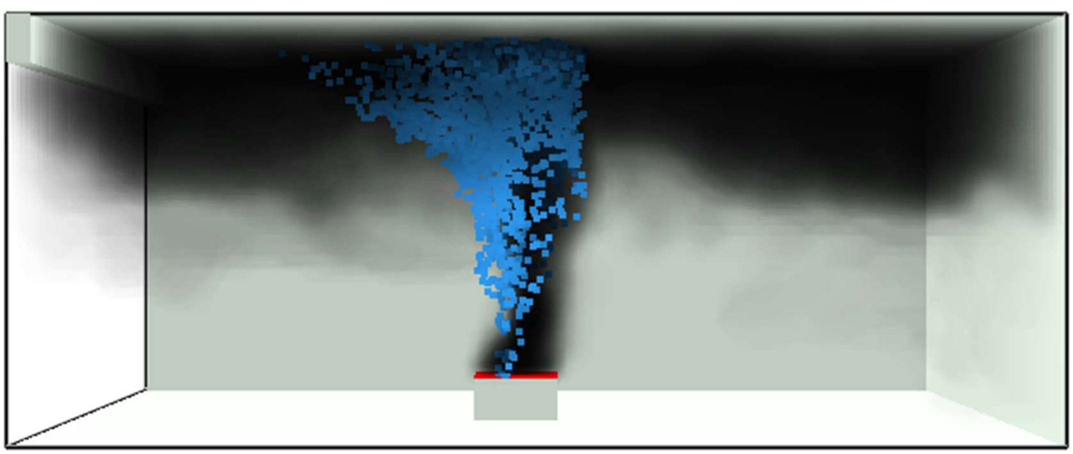


Figure 142: Suppression activation for the FDS truck fire.

What is obvious from Figure 142 is that most of the suppression water will not discharge over the fire. Furthermore, that portion of suppression water that is released over the fire will likely be carried away by the smoke plume or evaporate prior to reaching the base of the fire. This is easily validated as follows:

$Q = K * P^{1/2}$

Q = volume flow rate (GPM)

K = manufacturer assigned discharge coefficient

P = pressure of the water delivered to the sprinkler head (PSI)

The likely highest pressure to reach the suppression head directly over the fire if it is the only one activated is approximately 130 PSI. The volume at that pressure is calculated as follows:

$Q = 5.6 * 130^{1/2}$

$Q = 64$ GPM

Figure 141 shows that the HRR for the upper profile is at approximately 11 MW at the time of sprinkler activation. The latent heat of evaporation for this sprinkler discharge is calculated as follows:

*Energy to evaporate water = 64 GPM * 3.8 kg/gallon / 60 seconds/min * 2.26 MJ/kg*

Energy to evaporate water = 9.2 MW

If only 20% of the water from this sprinkler head is directed to the base of the fire, this 9.2 MW is reduced to 1.8 MW. This value is significantly lower than the 11 MW fire at the time of suppression activation, meaning that it is impossible for the suppression system to control this fire.

There may be some benefit for suppression in this high bay location for pre-wetting adjacent combustible crating, but the ceiling jet for the maximum HRR profile for the truck fire is expected to be hot enough to trigger multiple sprinkler heads over a large area that will reduce the overall pressure significantly to the point that suppression will provide no benefit to a growing fire. If combustibles are stored in this area, the fire will experience uncontrolled growth. This is why combustible control is vital to the fire safety strategy for this high bay location.

Sprinkler Activation in the Tool Room (PNNRA-117)

The DBF previously analyzed for the Tool Room for calculating the ASET is shown at the southwest section of Figure 111. The HRR profile for this fire is shown in Figure 114. The DETACT method was used to calculate suppression activation for this DBF. The range of sprinkler activation that correlates to this HRR profile based upon the DETACT method is shown in Figure 143. The location of this DBF is shown in Figure 115. Although the DETACT method did indicate suppression activation at approximately 10 minutes, FDS did not show that this fire would ever initiate suppression. The nature of the fire and high ceilings in the Tool Room suggest that suppression from an office workstation type of a fire may not ever trigger sprinklers. FDS was run at multiple locations in the Tool Room and did indicate suppression activation at lower ceiling heights. Given the sloped ceiling of the Tool Room, it is assumed that only limited activation occurs for the typical fires in this location. This demonstrates the importance of combustible control. Additional analysis will be performed in this report regarding fire spread and will also demonstrate the necessity of spacing the combustibles in separate islands to ensure fire does not spread in this location.

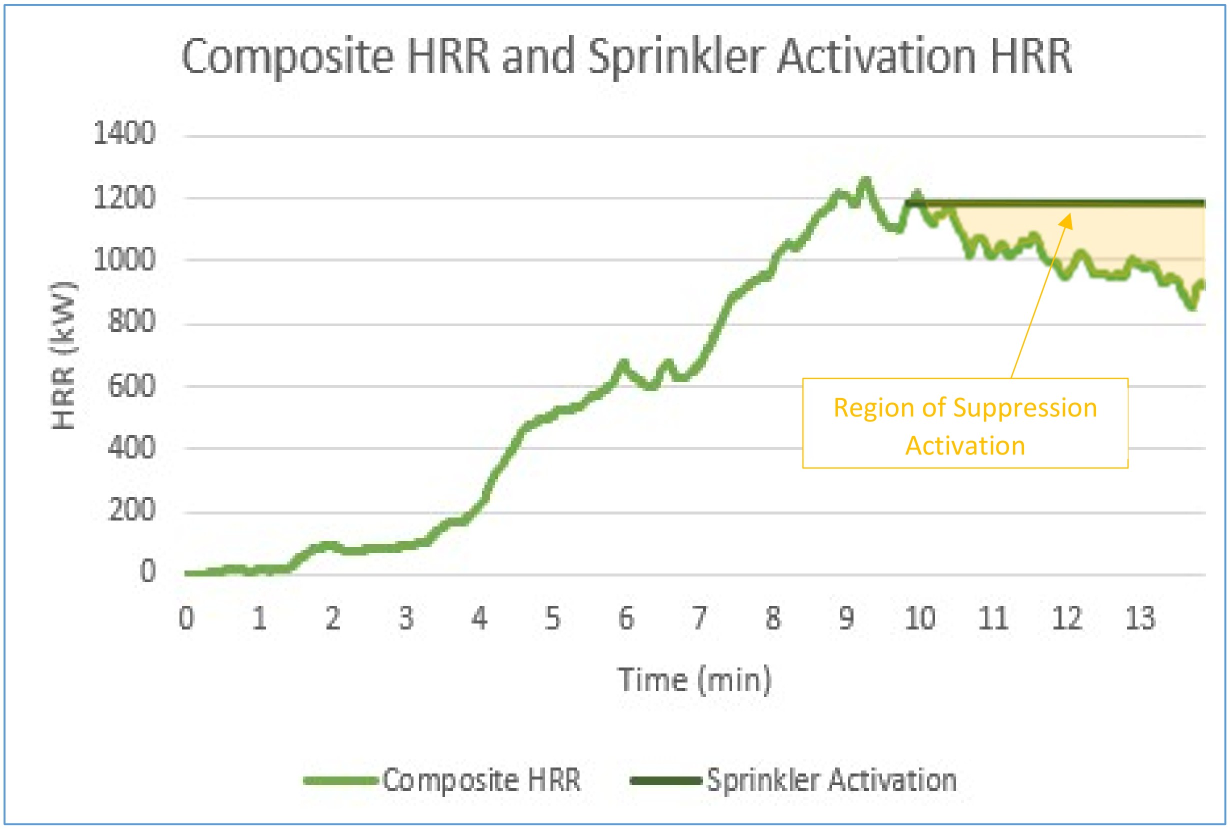


Figure 143: Sprinkler activation using the DETACT method for the DBF in the Tool Room.

Sprinkler Activation in the Northeast Office Location:

The DBF previously analyzed for the office compartment at the northeast portion of Figure 111 is used in this analysis for calculating time for sprinkler activation for office compartments. The same HRR profile used previously as shown in Figure 114 is used in this analysis. Both FDS and the DETACT method were used to calculate suppression activation for this location. This suppression activation is overlayed in the HRR figure as shown in Figure 144.

The DETACT method estimated a delayed suppression activation in comparison to the FDS analysis. The lower ceilings in office compartments in comparison to either the high bay or Tool Room locations results in less entrained air and hotter ceiling jets that allow suppression heads to activate at much lower HRR values. Furthermore, the enclosed nature of an office compartment results in a hot upper smoke layer and reflected radiant thermal energy that heats up the area faster resulting in the sprinkler head reaching its activation temperature sooner. As shown in Figure 144, FDS triggers suppression at around 200 kW for the HRR profile shown in Figure 114. This is significantly less than the DETACT estimate of approximately 500 kW. The upper and lower graphed lines in Figure 144 are the αt^2 fire profiles shown in Figure 119 and are meant to show boundary conditions for fire scenarios. Regardless of the differences between the DETACT and FDS methods, suppression is shown to activate in this compartment and the fire is sufficiently small that the suppression will actively control any fire growth.

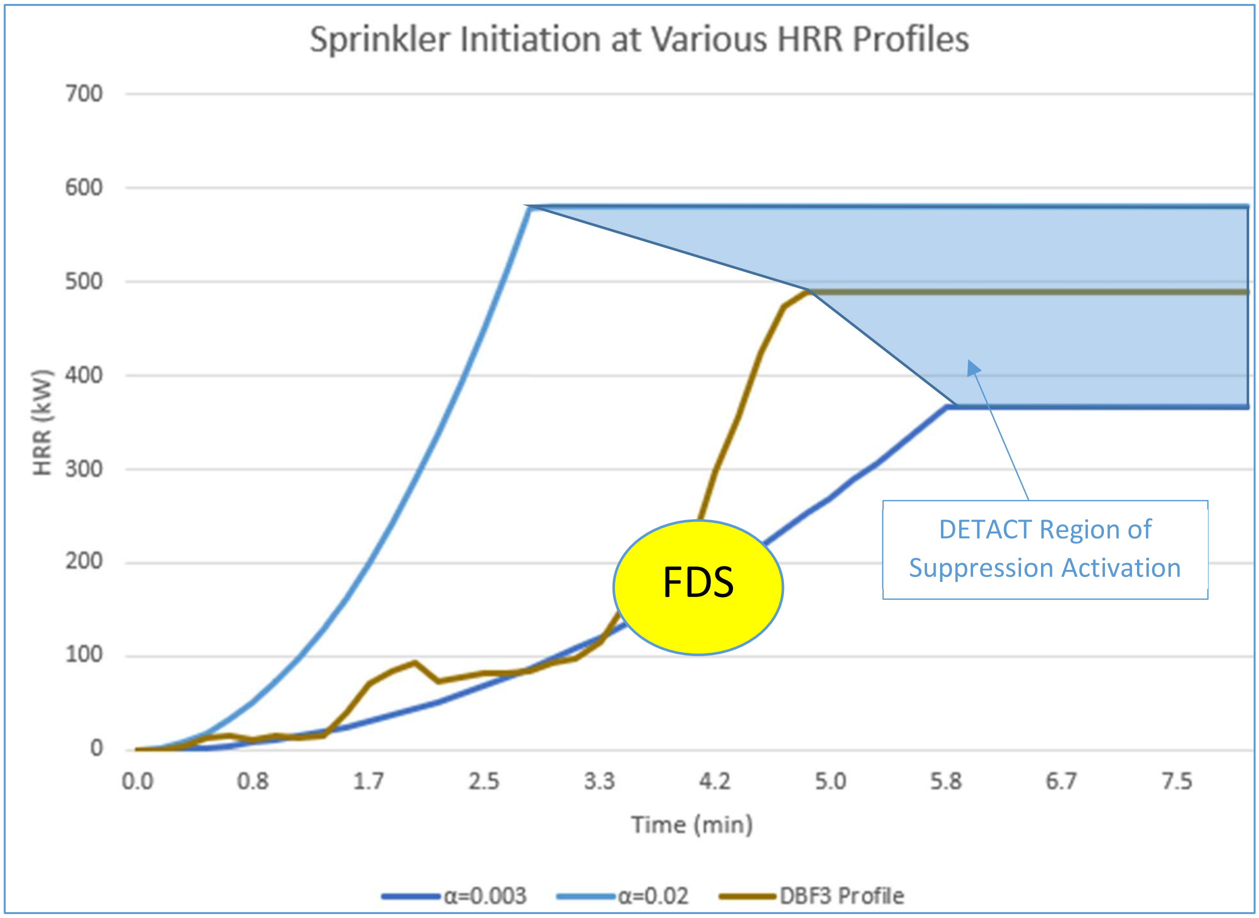


Figure 144: HRR profiles for the office compartment with the FDS and DETACT sprinkler activation areas.

Sprinkler Summary:
This analysis scrutinized the worst-case location in the ACME Building (Riser 3) as a bounding system and determined that the existing suppression systems will meet expected needs based upon design delivery requirements when these systems were installed. This is based upon the requirement for systems within the ACME Building to meet the design density and area requirements of an OH Group 1 system as a minimum.

Additionally, a performance-based analysis demonstrated that the SR K5.6 165° F sprinkler heads provide virtually no benefit in high bay locations and should not be relied upon for controlling fires. Further policy related actions are necessary for an in-depth fire safety strategy to be successful in this building that involves the elimination of combustible crating, pallets, and separation techniques to avoid the possibility of fire spread within high bay locations. Further analysis will be performed in this document that calculates the potential for fire spread from a truck fire, which will itemize additional recommendations.

This suppression activation section also reviewed a performance-based analysis of the Tool Room's suppression system. This location is concerning because of the large combustible loading. Reference (u) defines the type of storage at this location as low-piled storage. That type of storage requires an OH1 suppression system for up to Class II commodities, which are defined as non-combustible products in combustible packaging. This area is mostly Class II; however, the overall load is likely higher than this designation because of storage of PPE and plastic packaging that elevates the commodity class to Class III. Reference (u) requires an OH Group 2 system for this level of commodity protection. The OH2 system requires 33% more water discharge than the OH1. It is possible that the Tool Room suppression system provides an OH2 system because of the higher pressure to the POC that the 2021 flow tests established but detailed hydraulic calculations are necessary to verify that.

There is a mix of 212° F and 165° F heads in this area; although, most heads in this area, as illustrated in the Riser 9 section above as shown in Figure 135, are rated as 212° F. The DETACT and FDS analysis for this location used the lower 165° F rated sprinkler heads for the results shown in Figure 143 that indicated a 10-minute activation time for the DETACT method and no activation for the FDS method when the ceiling height was 20-feet for the HRR profile shown in Figure 114. The placement of higher temperature heads means a longer time for activation. Furthermore, the feed main and riser serving this system are both four inches in diameter, which could potentially restrict the flow in comparison to other risers serving the ACME Building. Significant care should be taken in organizing the storage of this area to ensure the suppression system can adequately control fires in this area. Additional analysis will be performed regarding fire spread in a subsequent section that will make more recommendations regarding storage configurations.

FIRE SPREAD ANALYSIS

This section examines the potential for fire spread within the locations analyzed for the truck fire shown at the location in Figure 108 and the Tool Room fire located at the southwest portion of the image shown in Figure 111.

Truck Fire:

The truck fire DBF HRR is shown in Figure 109 and represents two bounding fire scenarios. For this analysis to determine flame spread to adjacent combustibles, the truck fire is modeled as a flame sheet. The height of the flame is estimated as follows:

$L = -1.02D + 0.23\dot{Q}^{2/5}$ [Reference (k) Eq. 11, Pg. 3-153]

L = height of the flame (m)

D = diameter of the fire source (m)

$D = 2(\text{area}/\pi)^{1/2}$ [Reference (k) Eq. 12, Pg. 3-153]

$D = 2((2.4\text{ m} * 4\text{ m})/3.14)^{1/2}$ [Fire area approximately 2.4 m X 4 m]

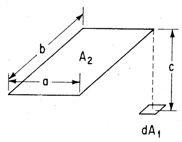
$D \simeq 3.5\text{m}$

$\dot{Q}$ = total HRR (kW) [Using 29 MW due to the short duration of the 31 MW PHRR]

$L = -1.02 * 3.5\text{ m} + 0.23 * 29{,}000^{2/5}$

$L \simeq 10\text{ m}$

The location of incidental heat flux for this analysis is a target on the upper side of a wood crate that is approximately centered from the fire at 2 m above the ground. The configuration factor evaluation is as follows:



$$F_{d1-2} = \frac{1}{2\pi}\left\{\frac{A}{(1+A^2)^{\frac{1}{2}}}\tan^{-1}\left[\frac{B}{(1+A^2)^{\frac{1}{2}}}\right] + \frac{B}{(1+B^2)^{\frac{1}{2}}}\tan^{-1}\left[\frac{A}{(1+B^2)^{\frac{1}{2}}}\right]\right\}$$

1) a = 2 m, b = 2 m, c = 3 m: configuration factor (ϕ_1) = 0.089
2) a = 2 m, b = 2 m, c = 3 m: configuration factor (ϕ_2) = 0.089
3) a = 2 m, b = 8 m, c = 3 m: configuration factor (ϕ_3) = 0.136
4) a = 2 m, b = 8 m, c = 3 m: configuration factor (ϕ_4) = 0.136

$\phi = \phi_1 + \phi_2 + \phi_3 + \phi_4$
$\phi = 0.45$

The typical average flame temperature is estimated at approximately 1,000° C [Table 5.6.5.1 2021 NFPA 921]. Crating is administratively prohibited from being within 10-feet (3 m) of the truck. Applying the Radiation Transport Equation with absorptivity/emissivity (ε) of 1, emitting body temperature (T_t) of 1,300 K, ambient temperature of 300 K (T_a), and the configuration factor of 0.45, the following incidental heat flux at 3 m away is identified:

$\dot{q}'' = \phi\, \varepsilon\, \sigma\, (T_t^4 - T_a^4)$; [$\sigma = 5.67(10^{-11})$ kW/m^2-K^4 Reference (k) Pg. 2-12]
$\dot{q}'' = 0.45 * 1 * 5.67(10^{-11})\,(1{,}300^4 - 300^4)$
$\dot{q}'' = 73$ kW/m^2

The estimated Critical Heat Flux (CHF) of wood crating is 10 kW/m^2 [Reference (h) Table A.35]. The CHF value is the minimum incidental heat flux that can result in piloted ignition. In actual fires, a time-lag is associated with applied heat flux, even if that incidental value is above the CHF. Regardless, this analysis conservatively assumes that if the incidental heat flux exceeds the CHF, ignition will start.

As the calculated incidental heat flux is approximately 73 kW/m^2 for the worst case PHRR for the worst-case upper boundary for the HRR fire model, it is assumed that fire will spread to the adjacent crating when such crating is staged 3 m away from the truck fire.

A safe distance for crating storage around the truck can be calculated by estimating the minimum configuration factor to just reach the CHF value of 10 kW/m^2. That calculation is as follows:

10 kW/m^2 = $\phi * 1 * 5.67(10^{-11})\,(1{,}300^4 - 300^4)$
$\phi = 0.062$

Iteratively solving for the distance away, the safe storage distance from the fire is 13 m away. This is the distance at which the incidental thermal radiation is under the CHF value for the worst-case upper PHRR from the truck fire.

The PHRR that the lower HRR truck fire model estimates is based upon the two-sedan fire and is 5.5 MW as shown in Figure 109. The estimated fire spread is calculated for this lower PHRR as follows:

$L = -1.02 * 3.5\ m + 0.23 * 5{,}500^{2/5}$
$L \simeq 3\ m$
Reevaluating the configuration factor gives:
$\phi = 0.285$
$\dot{q}'' = 0.285 * 1 * 5.67(10^{-11})\ (1{,}300^4 – 300^4)$
$\dot{q}''$ = **46** kW/m^2

As 46 kW/m^2 is above the CHF value of 10 kW/m^2, the fire will spread even in the best-case scenario. This fire spread will result in a higher overall HRR that could reach the minimum HRR to initiate sprinklers if the combustible loading is sufficient. As previously analyzed, this lower HRR profile for the two-sedan fire is insufficient to trigger suppression in the high bay by itself, but a spreading fire could reach a size to activate sprinklers. As previously stated, such a large fire would likely overpower the suppression system and be uncontrolled until fuel is exhausted.

Due to the size of the truck fire HRR, it is expected that multiple adjacent crates will ignite, and fire will spread through stored items in this area. Flashover conditions are not expected in the high bay due to the size of the high-bay area. Tenability is expected to be maintained so crane operating personnel can safely egress below the smoke layer. Personnel on the main floor of the high bay can safely egress due to the large and open nature of this area.

Tool Room Fire
The Tool Room fire is modeled per the HRR profile shown in Figure 114. This fire has a PHRR of 1.6 MW as shown in that figure. The incidental heat flux from this fire is evaluated in two different ways: the Point Source method and by using the Radiation Transport Equation.

The center of the fire is approximately 15-feet (4.5 m) from the closest location on the storage island with the face of the crating perpendicular to the fire.

Point Source Evaluation
$\dot{q}'' = 1{,}600\ kW * 0.3 * 1 / (4\pi * 4.5^2)$
$\dot{q}''$ = **2** kW/m^2

Radiation Transport Equation
$L = -1.02D + 0.23\dot{Q}^{2/5}$
$D = 2((3\ m * 3\ m)/3.14)^{1/2}$
$D = 3.4\ m$
$L \simeq 1\ m$
$\phi = 0.044$
$\dot{q}'' = \phi\ \varepsilon\ \sigma\ (T_t^4 – T_a^4);$
$\dot{q}'' = 0.044 * 1 * 5.67\ (10^{-11})\ (1{,}300^4 – 300^4)$
$\dot{q}''$ = **7** kW/m^2

The estimated CHF for the wood crating is 10 kW/m^2. Given that both the point source method and the Radiation Transport Equation give heat flux values below the CHF, combustibles in islands separated by at least 10’ from the edge of the Tool Room attendant’s area are not expected to combust.

Although the Tool Room design fire started at a trashcan that was ignited from a personal electric heater, that fire will grow and spread in a localized area. This analysis provides reasonable confidence that such a fire at the Tool Room attendant’s work area may not spread to adjacent stored combustibles if reasonable distance is maintained and good combustible controls policies are enforced. The suppression analysis for this Tool Room area that was previously performed concluded that suppression may or may not be initiated from such a workstation fire. The result of this fire will be that it will continue to burn until the fuel supply runs out, or the fire is controlled by manual firefighting operations or the fire spreads locally until suppression is activated.

The suppression system in this area is not designed for the class of commodities stored here. Additional precautions need to be taken to ensure the stored items and the structure remain safe. Reference (u) defines the low-piled storage configuration as storage that does not exceed 12 ft in height.

Suppression systems for OH1 layouts are designed to supply water for at least 1,500 ft^2. This design area can protect stored commodities if separation exists between piles. If a pile ignited, the separation distance between different piles will keep fire from spreading and allow suppression to control the pile that is on fire. Such a pile size of Class II commodities is expected to be controlled by an OH1 suppression system without being overpowered, as the system will be able to pre-wet adjacent combustibles and prevent spread due to both the pre-wetting action of the suppression and the separation between piles. Table 13.2.1 of Reference (u) specifies that a Class II commodity can be controlled by an OH1 system provided the pile heights do not exceed 10-feet in a low-piled storage configuration. Exceeding that height or commodity classification requires the suppression system to be designed with an OH2 configuration. Although such a design configuration may have the same area for discharge, it requires 0.2 GPM/ft^2 instead of the 0.15 GPM/ft^2 that the OH1 system specifies. As previously stated, the Riser 9 system shown in Figure 135 for the Tool Room was designed to meet OH1 water-flow requirements but may meet OH2 density because of the higher flow delivered to the POC. More analysis would be necessary to determine that. In the absence of that analysis, precautions should be taken for the storage of commodities in the Tool Room.

The commodity classification for the items stored in the Tool Room reflects a Class II commodity for the most part. Unfortunately, there are several items stored in this area that reflect a higher classification such as Class III, Class IV, and Group A plastic commodities. The likely overall classification is reflected by the definition of a Class III commodity as follows:

> *A product fashioned from wood, paper, natural fibers, or Group C plastics with or without cartons, boxes, or crates and with or without pallets. A Class III commodity shall be permitted to contain a limited amount (5%) of Group A or Group B plastics.*

The Tool Room has an OH1 suppression system with a Class III commodity classification. This configuration is not in compliance with Table 13.2.1 of Reference (u). It would be compliant if the suppression system had an OH2 water-flow.

There are two methods to handle storage in this area to better manage the potential for fire spread:

1) Keep overall combustible loading below the typical office environment.
2) Maintain separated islands of piled stored items.

Method 1 above is still subject to a TFM as described in the DBF2 section of the "PERFORMANCE BASED FIRE BARRIER ANALYSIS" section above. A TFM can burn in the absence of suppression resulting in prolonged exposure of structural steel to hot gases. The analysis performed in that section verified structural failure if a TFM was permitted to exist in the absence of suppression. Method 1 is reflected by other portions of the ACME Building that are used as office space. The typical fuel load for an office space is 750 MJ/m^2 (66,000 BTU/ft^2). Reference (k) Pages 18-6 – 18-7 specify 100,000 BTU/ft^2 as a reasonable value for a moderate fuel load, so the 66,000 BTU/ft^2 represents a conservative approach and is appropriate for this large area with high ceilings that delay suppression activation.

Method 2 relies on islands to store materials. The Miscellaneous Storage definition in Reference (u) uses an island size of 1,000 ft^2, where each island is separated from its adjacent island by at least 25'. The application of Miscellaneous Storage rules is designated for incidental storage of commodities necessary for the use of the primary occupancy type, such as a Group F-1 relying on adjacent feedstock. The Tool Room is separated from the rest of the facility by a two-hour barrier and is a dedicated storage facility, so the Miscellaneous Storage rules regarding pile sizes and offsets are not required.

It is recommended that an island storage paradigm be adopted in this area because of the higher commodity classification than what the suppression system supports. The recommendation is to use rows that are no more than eight-feet in width where each row is separated by 10-feet. The row length should not exceed 85-feet without a break of 10-feet. The storage height shall not exceed 12-feet.

Sprinkler Analysis Conclusion

<u>Tool Room</u>

The Tool Room does not meet the expectations for combustible loading and configuration in accordance with Reference (u). The following actions are recommended:

1) Reduce the overall combustible loading to under 66,000 BTU/ft^2. Existing policies provide an explanation for how to calculate combustible loading.
2) Use storage islands separated by 10-feet.

<u>West High Bay</u>

This analysis demonstrates that a truck fire will result in fire spread if combustibles are in the vicinity of the parked truck within the west high bay location. Change the existing policies by either not introducing the truck into this facility, or by changing the policy regarding the combustibility of the items stored in this area. Class I commodities are permitted as defined within Reference (u) as non-combustible products in non-combustible packaging. Do not use combustible crating or pallets. The other option is to separate such combustible items by 13 meters from the truck as specified in the analysis previously performed. A truck fire may result in structural damage depending on where it is parked; however, the larger concern is fire spread. By eliminating combustibles from this area, fire spread is much less likely to occur.

Other Locations

Other locations besides the Tool Room and the truck location are not examined in detail for fire spread within this report. Such locations do not pose as large of a risk as the two locations previously identified. Trucks are routinely used in the southeast portion of the building (PNNRA-438), but the ceilings are 50% higher and there is a smaller combustible loading. The same policies recommended for the west high bay should also apply to where the truck is parked in PNNRA-438 regarding combustible minimization. Additionally, this document has demonstrated the nature of flashover potential for office compartments. It is recommended to minimize combustibles by using metal cabinets and eliminating unnecessary combustible storage within office areas.

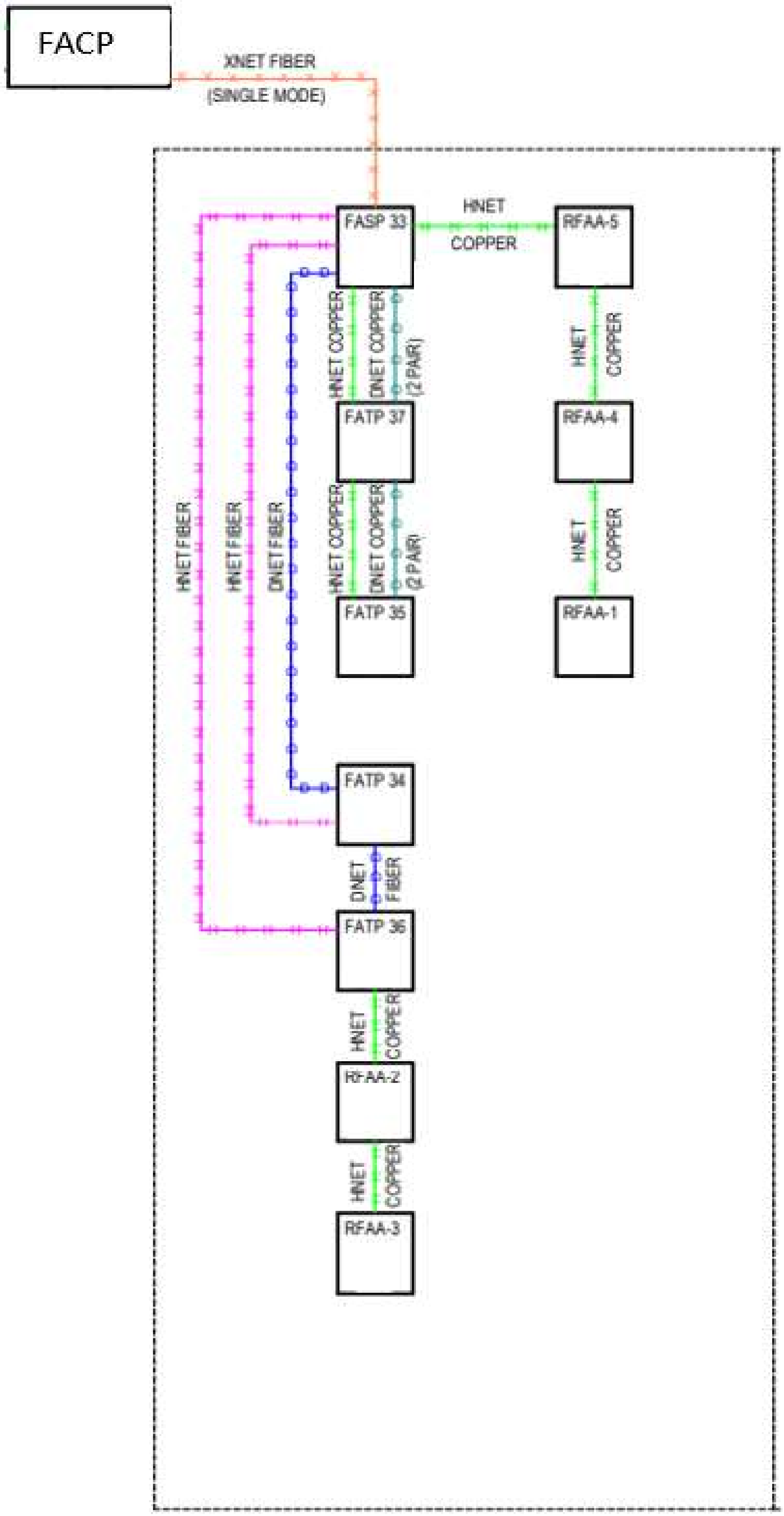


Figure 145: Components of the ACME Building FAS.

FIRE ALARM AND DETECTION SYSTEMS

The Code of Record (COR) for the current FAS is the 2010 NFPA 72, Reference (x). For convenience, the 2016 NFPA 72, Reference (y), will be referenced for this analysis. It is assumed that if this system is compliant with this more recent standard, it will be compliant with the COR.

the ACME Building has a manual FAS, with Manual Pull Stations (MPS) located within five feet of all unsecured exterior doors and at strategic locations along the MOE within the building structure. Heat detection is provided through sprinkler heads installed in accordance with Reference (u). The sprinkler system risers have water flow devices that are monitored by the FAS. Limited automatic smoke detection is provided by smoke detectors mounted above the four sub-main Fire Alarm Transponder/ Signaling Panels (FATP/FASP) located throughout the building, and the main Fire Alarm Signaling Panel (FASP), located on the north side of the building, just south of the middle entrance. Air ducts are also monitored by automatic smoke detectors. Automatic door closers also have smoke detectors mounted near them.

The sub-main FATP/FASPs communicate signals to the main FASP, which forward these signals to a central Fire Alarm Control Panel (FACP) in the administration building.

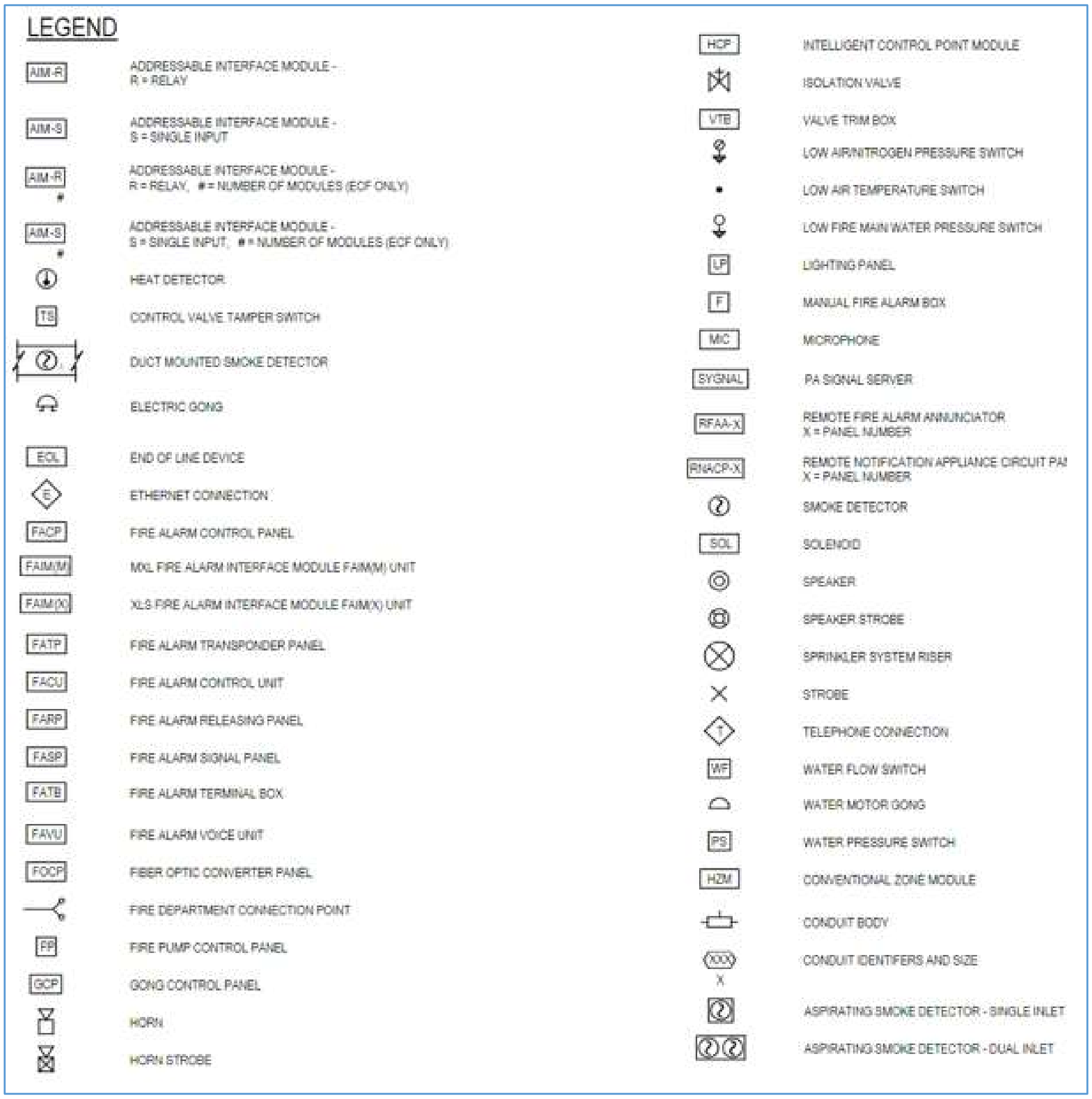


Figure 146: Legend for FAS symbols.

Other buildings surrounding the ACME Building have their own respective FATPs installed within them that also forward their signals to respective FASPs and then on to the central FACP. All the FATPs, FASPs and the FACP are a part of the overall FAS that serves PNNRA. The FAS is the Siemens Fire Finder - XLS system. The Fire Finder XLS system's Person Machine Interface (PMI) is used for programming and monitoring the installed alarm system. The PMI allows viewing of system data and conditions as well as providing a means for both automatic and manual system control. Siemens Zeus Programming Software is used as the platform within the PMI for programming the logic for the FAS.

The FACP communicates directly to the Fire Alarm Emergency Dispatch Center (FAEDC) that serves the PNNRA. This communication is through phone lines, which are connected to the Digital Alarm

Communication Transmitter (MDACT) card within the FACP. Communications between the FATPs, FASPs and the FACP is via the XNET and HNET communications protocol as shown in Figure 145.

The Desigo server is located next to the FACP in the administration building and gives system operators convenient control of the FAS. This Desigo server is like the PMI but provides a more convenient user interface. It provides functions to allow the user to see fire alarm conditions from the server's clients and perform tasks such as acknowledging signals and resetting panels across the additional buildings served by the FAS. The Desigo server is also available in the CSE's office.

the ACME Building also has five Remote Fire Alarm Annunciators (RFAA) throughout the building located near the main entrances that give the status of the system so first responders can identify where emergency signals are coming from.

TYPE AND LOCATIONS OF FIRE DETECTION DEVICES
The maps below show the individual design areas of the FAS system installed throughout the ACME Building.

Figure 147: First floor map of the ACME Building FAS.

The FAS was replaced between 2014 and 2016. As part of that installation, the system was upgraded to meet the requirements of the Reference (x) requirements. The FAS review of the ACME Building as part of this analysis involved inspecting the entire system for general compliance. A more elaborate analysis is being performed on a subset of the whole FAS in the ACME Building to ensure code compliance was maintained in the design.

Areas 1 and 2 of the first floor shown in Figure 147 and Area 1 of Figure 148 will be scrutinized for Reference (y) code compliance. It is reasonable to assume that a careful examination of a portion of this system will demonstrate code compliance that was applied for the entire system. The as-built drawings for these three areas are shown below as Figure 149, Figure 150, and Figure 151. This subset is being scrutinized with the assumption that if the installation for this sample of areas is correct, the remainder of the facility is correct. This assumption is valid due to the recent installation of the FAS and the rigorous inspection and oversight process that went into this design and installation.

Areas 1 and 2 in Figure 147 and Area 1 in Figure 148 have initiating devices that include five MPS (Siemens HMS-M; #500-033450), four photoelectric Smoke Detectors (SD) (Siemens HFP-11; #500-033290), one riser Water Flow (WF) device and one riser valve Tamper Switch (TS). Technical specification sheets for these components are included within Appendix C.

[redacted]

Figure 148: Second floor map of the ACME Building showing the FAS.

Initiating Device Compliance with Reference (y)

The two MPS's in Area 1 of Figure 147 (main floor of the west high bay) are located within five-feet of the respective exit exterior doors in accordance with Section 17.14.8.4 of Reference (y). The two MPS's in Area 1 of Figure 148, which shows the upper areas of the west high bay, are placed on a catwalk for crane access. The west side crane access walkway MPS is placed for convenience in the event a fire occurs within the crane or is otherwise viewed from the operators' booth. It is mounted so that a crane operator can immediately exit the operator's box and trigger an alarm if the crane or some location visible from the crane is on fire. It is not required by Reference (y). The MPS on the east side of the crane access catwalk of Area 1 is to meet the Section 17.14.8.5 requirement that an MPS shall be within 200-feet of travel distance from any point. All four MPS' are installed with their operable part between 42" and 48" AFF meeting the requirement of Section 17.14.5.

Area 1 of the high bay has four automatic smoke detectors. Although the ACME Building is not set up for fully automatic smoke detection, Reference (y) requires smoke detectors to support certain conditions. Two of the four smoke detectors are used with a door-closer assembly and are mounted to automatically trigger the closing of a roll-up fire door that separates PNNRA-517 from PNNRA-117. These two wall mounted detectors are installed next to the door and are assumed to comply with Section 17.7.5.6.5.1(A) of Reference (y), which specifies that door-frame integral detectors shall be installed in a manner recommended by the manufacturer. The assumption of detector placement meeting manufacturer specification is based upon the original placement of the detectors for this door. It is assumed that the location for the smoke detector placement was accepted by the Authority Having Jurisdiction (AHJ) when installed.

The third smoke detector to the west of the roll up door, is mounted next to an annunciator control panel as required by Section 10.4.4 of Reference (y). The fourth smoke detector is on the south wall next to a fire alarm panel and is code compliant.

The Water Flow switch in Area 1 of Figure 147, that monitors water flow through the riser at this location (suppression system 9) has been tested to ensure that it activates within 90 seconds from water being released from the smallest orifice in accordance with Section 17.12 of Reference (y). The smallest orifice for this sprinkler system is a ½” sprinkler head (K5.6) that is releasing approximately 15 gallons per minute.

The riser valve that supplies water to this suppression system has a tamper switch installed to supervise its position in accordance with Reference (u), Section 8.16.1.1.2.1.

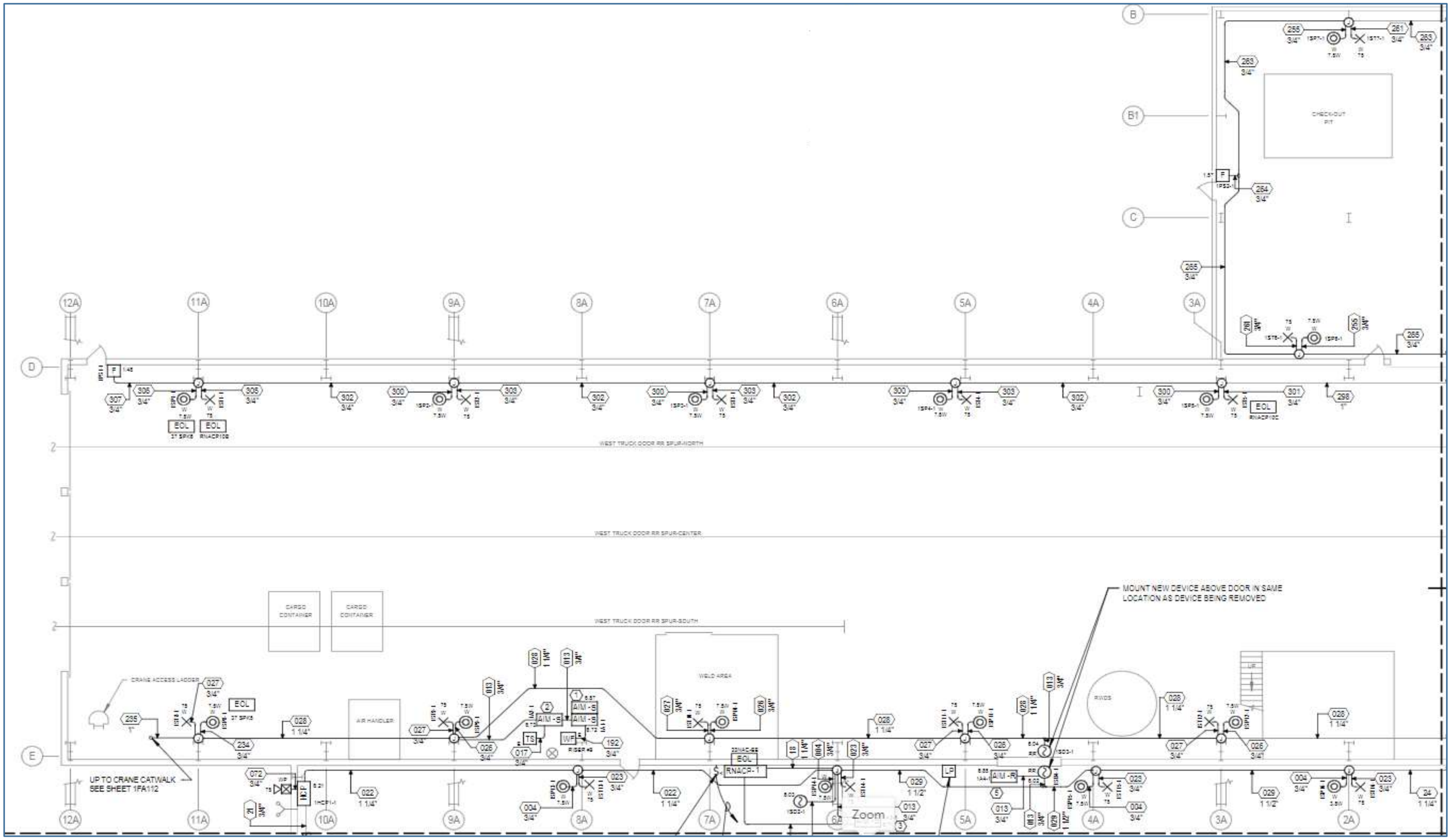


Figure 149: As-Built drawing for the first-floor Area 1 of the ACME Building FAS.

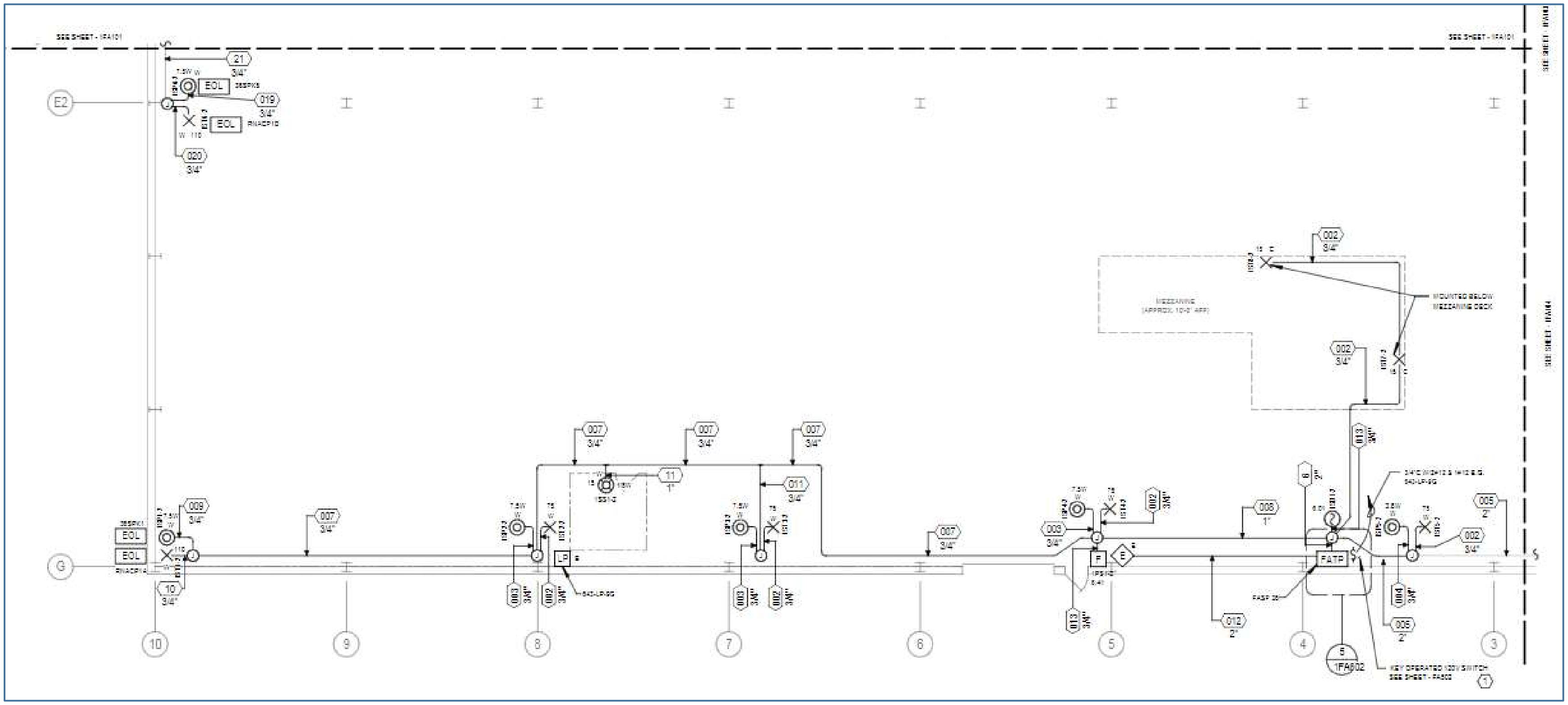


Figure 150: As-Built drawing for the first-floor Area 2 of the ACME Building FAS.

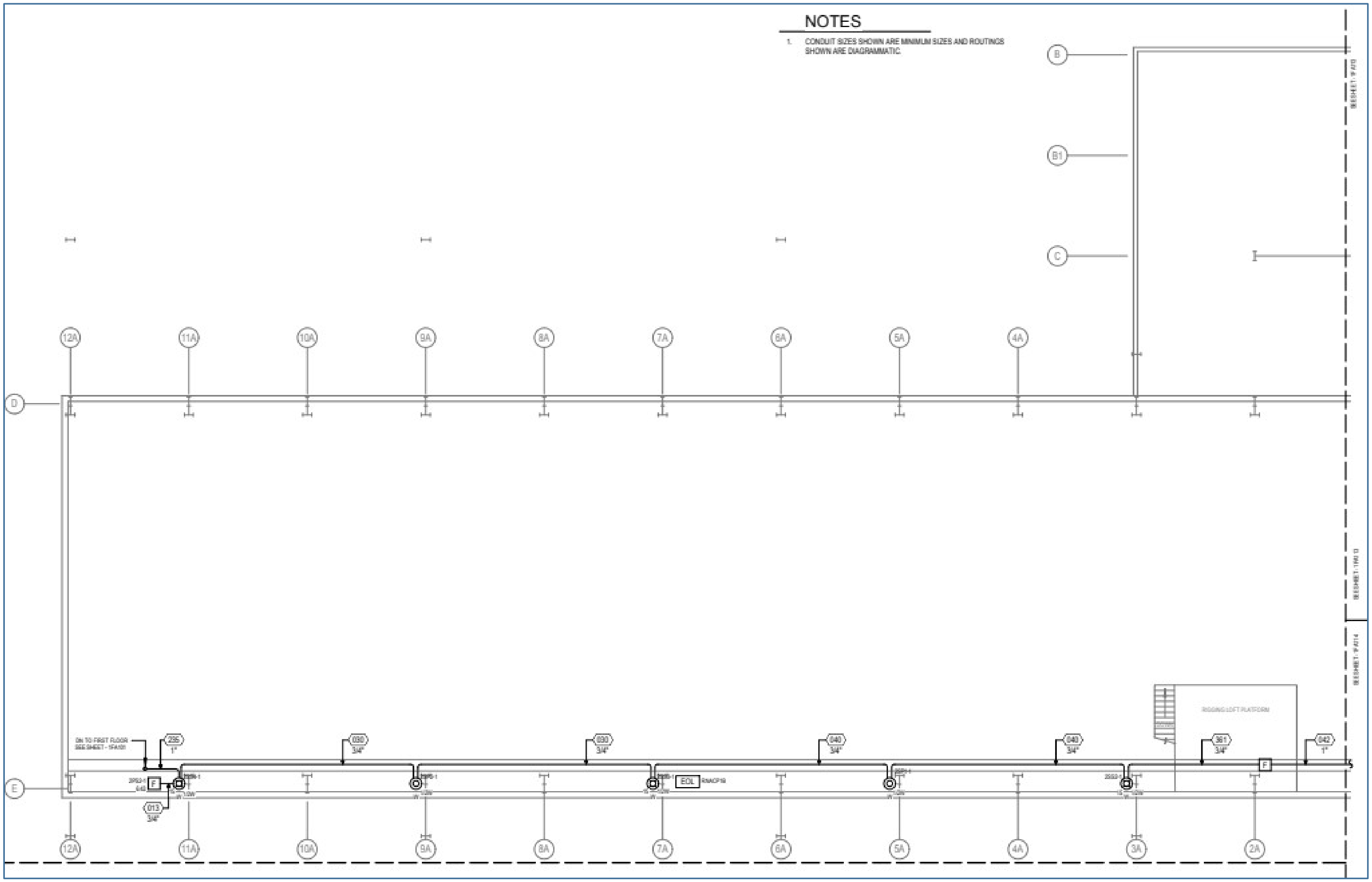


Figure 151: As-Built drawing for the second-floor Area 1 of the ACME Building FAS*.*

Fire Scenarios and Expected Response Characteristics

The sprinkler heads installed within the ACME Building act as heat detectors and will be used as the initiating devices for this analysis. The sprinkler heads over Area 1 of Figure 147 are approximately 60-feet (18.3 m) AFF. The installation of this sprinkler system used SR K5.6 165° F sprinkler heads. According to Reference (u), Section 3.6.1, standard response sprinklers have a Response Time Index (RTI) rating of 80 (meter seconds)$^{1/2}$ or more. The RTI value of 80 shall be used for this portion of the analysis to estimate how long it takes for a suppression head to activate that can trigger a flow switch in a riser for a gasoline spill related fire.

A bounding DBF for this scenario involves a worst-case gasoline spill of 15 gallons on the ground inside Area 1. Gasoline has a shallower spill depth and larger spill area than diesel. It also is consumed faster creating a much hotter fire than the diesel pool fire previously analyzed. This DBF analysis assumes no stratification of hot gases from this fire due to the high thermal power output from this DBF. It also assumes that the gasoline spill will have the entire volume spread out to its worst-case area before igniting. Furthermore, the gasoline ignition will be instantaneous and ignore the burn velocity (2 m/s) when it fully ignites. The gasoline spill is assumed to cover a smooth area without floor voids that allows this spill to reach a maximum area. Additionally, 80% combustion efficiency will be applied to this spilled gasoline fire. This will produce a hotter fire than the diesel pool fires previously used for DBFs.

The regional average temperature in July is 68° F where the ACME Building is located. Ambient air temperature within Area 1 is assumed to be 78° Fahrenheit (F) for this DBF.

RTI = 80 $m^{1/2}S^{1/2}$	Reference (u), Section 3.6.1
T_a = 78° F (25.6° C)	Ambient temperature
T_s = 165° F (73.8° C)	Sprinkler head temperature rating
T_g = Gas Temperature (C)	Temperature of gas flowing by sprinkler head
T_d = Detector temperature (C)	Temperature of Detector
Δt = Time step (s)	Time step for DETACT method
δ = Fuel Thickness (mm);	Gasoline pool thickness
δ_0 = 0.7 mm	Thickness of fuel at start (65.2a Reference (h))
$C_\delta = 0.95(1-e^{-0.71\delta})$	Fuel burn rate coefficient (65.22a Reference (h))
$\dot{m}'' = C_\delta * \dot{m}''_\infty$	Burn rate of fuel (65.20 Reference (h)) $[1-e^{-2.1*D}] = 1.0$ for D > 2.6 m
$\dot{m}''_\infty = 0.055\ kg\ m^{-2}s^{-1}$	Gasoline Burn Rate (Reference (h) Pg. 864)
Area (A) = Volume (V) * 0.003785 m^3/gal / (δ / 1000)	Derived equation for area
$\dot{Q} = \dot{m}'' * A * \Delta h_c$	Heat Release Rate (Reference (h) Pg. 2,580)
$\Delta h_c = 43.7\ MJ\ kg^{-1}$	Gasoline Heat of Combustion (Reference (h) Pg. 865)
$T_g = \left(\frac{16.9\ X\ Q^{\frac{2}{3}}}{H^{\frac{5}{3}}}\right) + T_a$	Gas temperature (Reference (h) Pg. 431)
H = 60' (18.3 m)	Approximate Height of sprinkler heads above AFF
$\rho_{gas} = 740\ kg/m^3$	Density of gasoline (Reference (h) Pg. 865)

$V = A*(\delta/1000) / (0.003785\ m^3/gal)$	Volume in Gallons of Unburned Fuel
$\Delta\delta = \dot{m}'' * \Delta t\ /\ \rho_{gas}$	Δ fuel thickness after Δt time of burn
$\mu = \left(\frac{0.947\ Q^{\frac{1}{3}}}{H^{\frac{1}{3}}}\right)$	Velocity of ceiling jet (Reference (h) Pg. 431)
$\frac{dT_d}{dt} = \frac{\mu^{\frac{1}{2}}(T_g - T_d)}{RTI}$	Change in head temp (Reference (h) Pg. 1,322)
$\Delta T_d = \frac{\mu^{\frac{1}{2}}(T_g - T_d)}{RTI}$	Above equation with t = 1 second
$T_{d(n)} = \Delta T_{d(n-1)} + T_{d(n-1)}$	Temperature of Sprinkler head
$\delta_{i+1} = \delta_i - \Delta\delta_{i+1}$	Depth of fuel at t = i

The sprinkler head spacing in Area 1 is based upon an OH placement. The horizontal distance from a fire (R) to a sprinkler head shall be much less than the height (H) of the sprinkler head AFF. The R/H ratio shall always be < 0.15, allowing the above formulas to be used.

It is assumed at time (t) = 0 seconds, that the fire has instantly started across the entire area of the gasoline fuel spill, conservatively ignoring the time for fuel spread and the volume of the fuel consumed during the ignition process. As the gasoline is burned, and due to the shallow thickness of this maximum sized spill, the initial heat output will be higher at t = 0 than at any other time. As the thickness of the fuel decreases, the cooling effect from the floor will impact the ability of the fuel to vaporize and will lower the overall output of the fuel consumption. This decrease will continue until all the fuel is burned, at which point, the fire will self-extinguish.

The sprinkler heads, which are acting as heat detectors, respond when their temperature matches their 165° F (73.8° C) rated temperature. A 15-gallon gasoline spill meeting the conservative assumptions stated above will cause a sprinkler head to release no sooner than 17 seconds after the burn has started. This is a minimum time for activation based upon the enumerated assumptions and likely significantly underestimates the actual time, which is more appropriately approximated as a few times this value. The results are summarized in Table 18.

Minimum Fuel Spill Volume over a Maximum Area

This same process used in estimating the time for sprinkler activation for a worst-case sized 15-gallon gasoline spill was used in evaluating what the minimum volume of gasoline required is to activate the sprinkler system by modifying the fire related parameters. The volume of gasoline in this worst-case spill scenario with the conservative assumptions as specified above is 12.7 gallons. If less than that amount of gasoline is spilled, the sprinklers will not receive enough heat to activate prior to the fuel completely burning. This is due to the high ceilings within this high bay that allow entrained air to mix with the smoke and cool before reaching the sprinkler heads. This is also due to the use of SR sprinkler heads originally installed at the ceiling. Using fast response sprinkler heads with a lower RTI will enable the sprinklers to activate with a smaller fire, but this would require an entire change-out of sprinkler heads within the high-bay locations and have minimal overall benefit. This 12.7-gallon minimum gasoline spill is also likely a much smaller amount than what is required to activate sprinkler heads due to the conservative assumptions in this analysis. A spill of gasoline in actual conditions would not create a uniformly large pool but would more likely puddle in recessed locations and around storage items and produce a lower energy output than a large and uniform pool fire. Furthermore, the 80% combustion rate assumption is likely more efficient than that what is expected from large pool fires, requiring a larger spill area to produce the same amount of energy output as the uniform 12.7-gallon fuel spill used in this example.

This gasoline spill example is performed simply to demonstrate differences between the two diesel pool spills previously analyzed along with the truck HRR profiles used to estimate sprinkler activation. This shows a range of potential scenarios. The gasoline is less viscous than diesel and creates a thinner but much larger sized spill that burns much more vigorously. In the case of the pool fires analyzed, the one take-away is that suppression activates because of the very high HRR due to the large area of the liquid fuel. That fuel quickly burns out on its own just after suppression is activated. This demonstrates why it is very important to keep the combustible loading to a minimum to avoid flame-spread to adjacent combustibles. These analyses demonstrate that the structure can survive with simple pool fire DBFs but may be damaged if combustible controls are not enforced. It also demonstrates that the FAS will trigger, and the automatic notification system will activate annunciators throughout the campus if a pool fire occurs because of the sprinkler riser flow switch.

Table 18: Table of values using the DETACT method for calculating sprinkler head activation. This is based upon a 15-gallon gasoline spill that is spread with a maximum spill area of 81 square meters.

Step	$T_g = \left(\frac{16.9 \times Q^{\frac{2}{3}}}{H^{\frac{5}{3}}}\right) + T_a$	$T_{d(n)} = \Delta T_{d(n-1)} + T_{d(n-1)}$	δ - Δδ (mm)	$0.95*(1-e^{(-0.716δ)})$	$C_δ$ * 0.055 (kg/m²s)	$\dot{m}''$ * A * Δh_c (kw)	A*δ / .003785 (gal)	$\dot{m}''$ * Δt / 740 kg/m³	0.947*Q^(1/3)/H^(1/3)	$\mu^{1/2}(T_g - T_d)$/RTI + T_{d0}
T (Δt = 1s)	T_g (Eq.1) (° C)	T_d (Eq. 2) (° C)	δ (Eq. 3)	$C_δ$ (Eq. 4)	$\dot{m}''$ (Eq. 5)	Q (Eq. 6)	V (Eq. 7)	Δδ (Eq. 8)	U (Eq. 9)	ΔT_d (Eq. 10)
0	139.51	25.60	0.70000	0.37206	0.02046	58024.50	15.00	0.0000277	12.44	5.02
1	137.16	30.62	0.67235	0.36061	0.01983	56237.40	14.41	0.0000268	12.31	4.67
2	134.81	35.29	0.64554	0.34928	0.01921	54471.52	13.83	0.0000260	12.18	4.34
3	132.47	39.64	0.61958	0.33811	0.01860	52728.76	13.28	0.0000251	12.05	4.03
4	130.14	43.66	0.59446	0.32709	0.01799	51010.89	12.74	0.0000243	11.92	3.73
5	127.81	47.40	0.57014	0.31625	0.01739	49319.55	12.22	0.0000235	11.78	3.45
6	125.50	50.85	0.54664	0.30558	0.01681	47656.30	11.71	0.0000227	11.65	3.19
7	123.20	54.03	0.52393	0.29511	0.01623	46022.56	11.23	0.0000219	11.51	2.93
8	120.92	56.96	0.50199	0.28483	0.01567	44419.62	10.76	0.0000212	11.38	2.70
9	118.66	59.66	0.48082	0.27475	0.01511	42848.66	10.30	0.0000204	11.24	2.47
10	116.42	62.14	0.46040	0.26489	0.01457	41310.71	9.87	0.0000197	11.11	2.26
11	114.20	64.40	0.44072	0.25525	0.01404	39806.71	9.44	0.0000190	10.97	2.06
12	112.01	66.46	0.42174	0.24583	0.01352	38337.43	9.04	0.0000183	10.83	1.87
13	109.84	68.33	0.40347	0.23663	0.01301	36903.56	8.65	0.0000176	10.70	1.70
14	107.70	70.03	0.38589	0.22767	0.01252	35505.63	8.27	0.0000169	10.56	1.53
15	105.59	71.56	0.36896	0.21894	0.01204	34144.08	7.91	0.0000163	10.42	1.37
16	103.51	72.93	0.35269	0.21044	0.01157	32819.22	7.56	0.0000156	10.29	1.23
17	101.45	74.16	0.33705	0.20218	0.01112	31531.26	7.22	0.0000150	10.15	1.09
18	99.43	75.25	0.32202	0.19416	0.01068	30280.30	6.90	0.0000144	10.02	0.96
19	97.45	76.20	0.30759	0.18638	0.01025	29066.34	6.59	0.0000139	9.88	0.83
20	95.49	77.04	0.29374	0.17883	0.00984	27889.29	6.29	0.0000133	9.74	0.72
21	93.58	77.76	0.28045	0.17152	0.00943	26748.97	6.01	0.0000127	9.61	0.61
22	91.69	78.37	0.26770	0.16444	0.00904	25645.12	5.74	0.0000122	9.48	0.51
23	89.85	78.88	0.25548	0.15760	0.00867	24577.40	5.47	0.0000117	9.34	0.42
24	88.03	79.30	0.24377	0.15098	0.00830	23545.40	5.22	0.0000112	9.21	0.33
25	86.26	79.63	0.23254	0.14459	0.00795	22548.65	4.98	0.0000107	9.08	0.25
26	84.52	79.88	0.22180	0.13842	0.00761	21586.63	4.75	0.0000103	8.95	0.17
27	82.82	80.06	0.21151	0.13247	0.00729	20658.74	4.53	0.0000098	8.82	0.10
28	81.16	80.16	0.20166	0.12673	0.00697	19764.38	4.32	0.0000094	8.69	0.04
29	79.53	80.20	0.19224	0.12121	0.00667	18902.85	4.12	0.0000090	8.56	-0.02
30	77.94	80.17	0.18324	0.11589	0.00637	18073.48	3.93	0.0000086	8.43	-0.08
31	76.39	80.09	0.17462	0.11077	0.00609	17275.52	3.74	0.0000082	8.31	-0.13
32	74.87	79.96	0.16639	0.10585	0.00582	16508.21	3.57	0.0000079	8.18	-0.18
33	73.40	79.78	0.15852	0.10113	0.00556	15770.78	3.40	0.0000075	8.06	-0.23

Disposition of Alarm, Supervisory and Trouble Signals

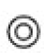
Three separate types of signals are received and processed by the FAS: Alarm Signals, Supervisory Signals, and Trouble Signals. Alarm Signals occur with the activation of a smoke or heat detector (indirectly through sprinkler heads), a manual pull station, or a water flow device. The Fire Department responds immediately to all such events. Supervisory Signals indicate that there is an issue with one of the systems that are interfaced with and monitored by the FAS. This condition monitors situations that include valve position tamper switches for the suppression risers, loss of power, and abnormal switch conditions. Upon receipt of such events, appropriate life safety personnel are notified, and the situation is investigated. Trouble Signals mean that there is something wrong with the FAS. This condition occurs when a system component has malfunctioned or a circuit with an end-of-line resistor is open and results in personnel investigating the situation to identify the necessary corrective actions. A Trouble signal is investigated with a lower priority than a Supervisory signal.

In an alarm event, the FAS will activate speaker-strobe devices within the ACME Building to notify local personnel of the condition. This will include the standard Temporal-Three pattern alarm notification along with a pre-recorded voice evacuation message notifying building occupants of fire conditions. Additionally, fire doors held open by electrical magnets will be released so fire barriers can be maintained. Ventilation systems are also shut down if alarm signals are received. Smoke detectors located in the return ducting for the ventilation system will trigger the FAS to perform an immediate shut down of fans supporting ventilation via listed fire alarm shunt trip relays. An alarm signal from the ACME Building will also cause the FAS to send out an announcement to the Public Address (PA) system for site-wide broadcast across PNNRA notifying personnel that a fire condition exists.

One unique design aspect of the ACME Building is that it lacks a robust smoke control system. Atriums such as the high bay are expected in new construction to have smoke vents at the ceiling to remove any smoke to improve ASET. Internal regulations prohibit this facility from having roof vents due to the potential for asbestos airborne events. The only smoke controls for this facility are the duct smoke detectors that shut down HVAC when smoke is detected, and the automatic door closers that shut doors to avoid smoke spreading throughout the facility.

ALARM NOTIFICATION DEVICES

The installed notification devices in Areas 1 and 2 being analyzed are identified below:



23 Wall Mount Speakers (Siemens S54360-F11-A1; SEH-R),

21 Wall Mount Strobes (Siemens 500-636169; ZR-MC-R, 500-636106; ST-75-R-WP),

1 Wall Mount Horn Strobe (Siemens 500-6366016; ZH-MC-R),

4 Wall Mounted Speaker Strobes: (Siemens S54860-F10-A1; SEH-MC-R)

The locations for these notification devices are shown in Figure 152 and Figure 153 below. These two figures are also shown in Figure 147 and Figure 148. Both the Signaling Line Circuit (SLC) and the Notification Appliance Circuit (NAC) are Class B. The SLC uses #16 American Wire Gage (AWG) twisted pair FLPR cables, while the NAC uses #12 and #14 AWG twisted pair FLPR cables. All conduit is Electrical Metal Tubing with a minimum diameter of ¾".

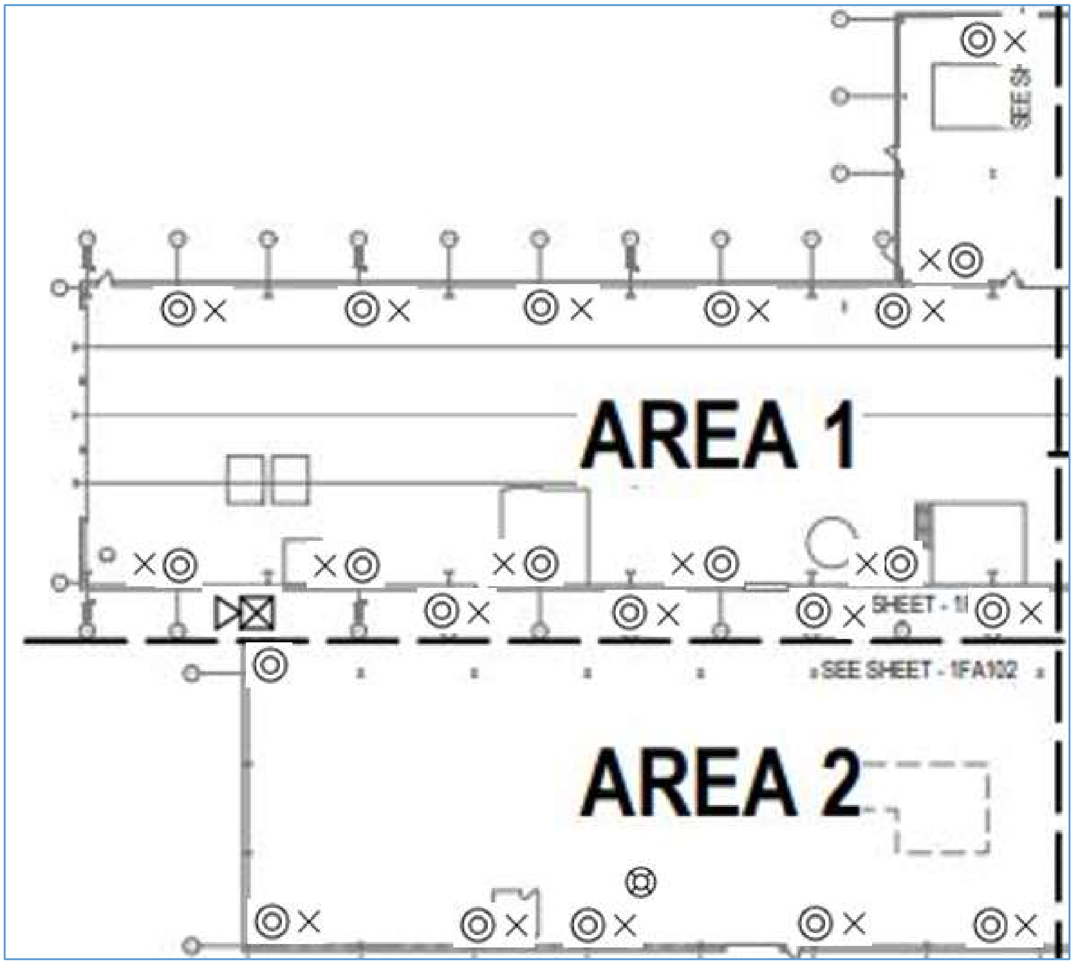


Figure 152: Annunciator layout for first floor Areas 1 and 2.

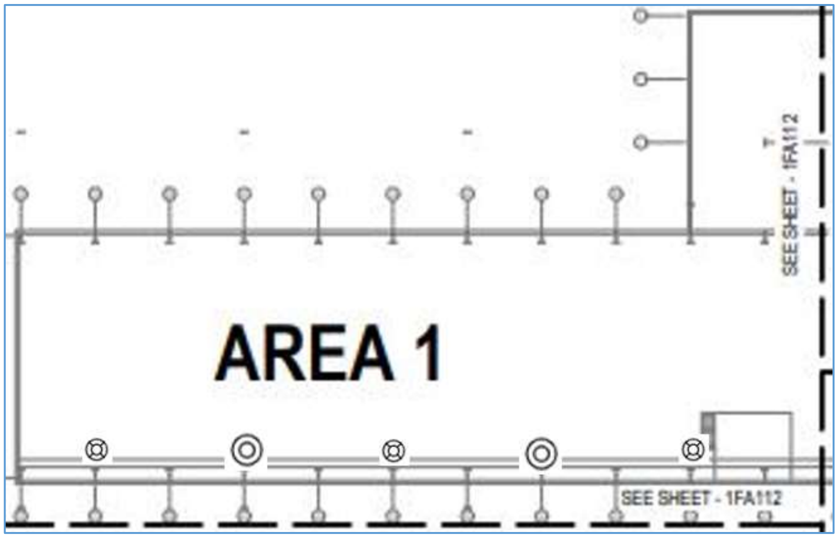


Figure 153: Annunciator layout for 2nd floor Area 1.

Code Compliance of Notification Appliances

Areas 1 and 2 of the first floor are open spaces. Sound and light have clear access through these areas, with minor interferences. The sound levels for the speakers were verified as adequate through audibility measurements conducted when the new FAS was installed. The audible notification appliances were designed for this Group F-1 occupancy for an ambient sound level of 60 dBA. The noise background for this area is atypical of other factory environments, as the work that is conducted here is more research based. This results in a minimum required emergency notification sound level of 75 dBA in the area that each speaker covers.

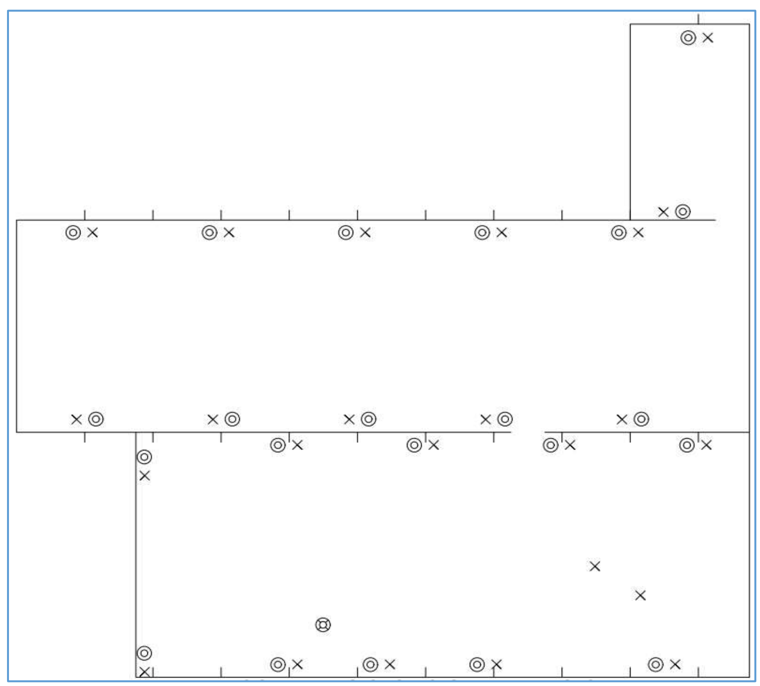


Figure 154: Notification appliance layout in Areas 1 and 2.

Areas 1 and 2 of the first floor are broken into three separate Acoustically Distinguishable Spaces. Each space has been qualitatively tested for intelligibility and has been accepted as adequate.

In all cases, the audible notification appliances are wall mounted and are no less than 90 inches AFF, and no less than six inches below the ceilings in accordance with Reference (y) Section 18.4.8.1.

The visible notification appliances are wall mounted where the entire lens is not less than 80 inches AFF and not greater than 96 inches AFF in accordance with Section 18.5.5.1. Reference (y) Figure A.18.5.5.4(c) shows that the correct strobe placement in rooms with multiple strobes should be off centered. The Areas 1 and 2 as shown in Figure 154 have strobes that do not have the recommended off-centeredness. This is not a code violation, but only a failure to adopt recommended practices.

Almost all the strobes are rated at 75 Candela (cd). Reference (y) Table 18.5.5.4.1(1) specifies that a 75-cd strobe can support an area of 45' X 45'. There are also two 110 cd and two 15 cd strobes in these areas. Figure 154 shows Areas 1 and 2 of the first floor with the notification appliances. Figure 155 shows each of the strobes in Figure 154 with a box around it representing the allowable area as defined in Table 18.5.5.4.1(1) of Reference (y). The solid green areas represent locations that are not covered by the permissible areas of the mounted strobes. The open environment of this warehouse permits adequate light from other visual notification appliances allowing occupants to clearly see when an emergency condition exists, so this situation on a principal basis still provides adequate coverage and the failure to cover these small cross-hatched areas is considered an insignificant violation.

Figure 156 shows the strobes for the crane access catwalk. These strobes protect a non-public area and are improperly sized to meet the needs of this entire upper cat-walk space if it was publicly accessible. The floor-level of Area 1 has adequate visual notification appliances, and the crane operators will have a clear view to the floor area allowing them to see these notification devices when triggered. The lack of catwalk strobes is not considered to be a violation because of the clear view to the floor level of the west high bay below the catwalk.

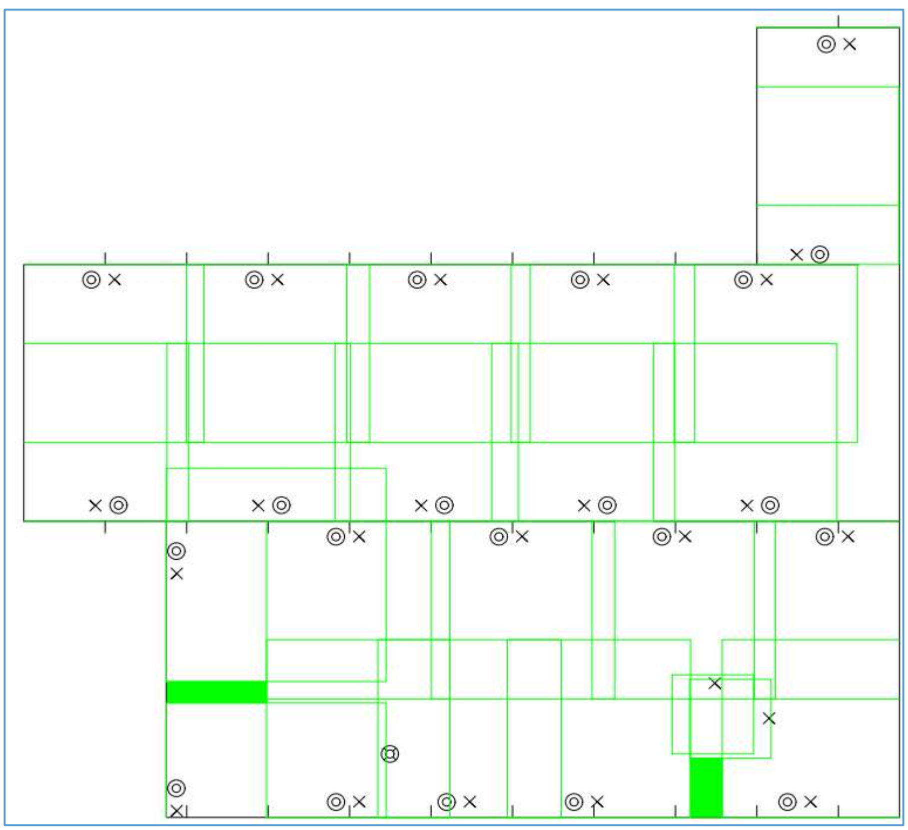


Figure 155: Areas 1 and 2 of the first floor showing areas of coverage for the strobes.

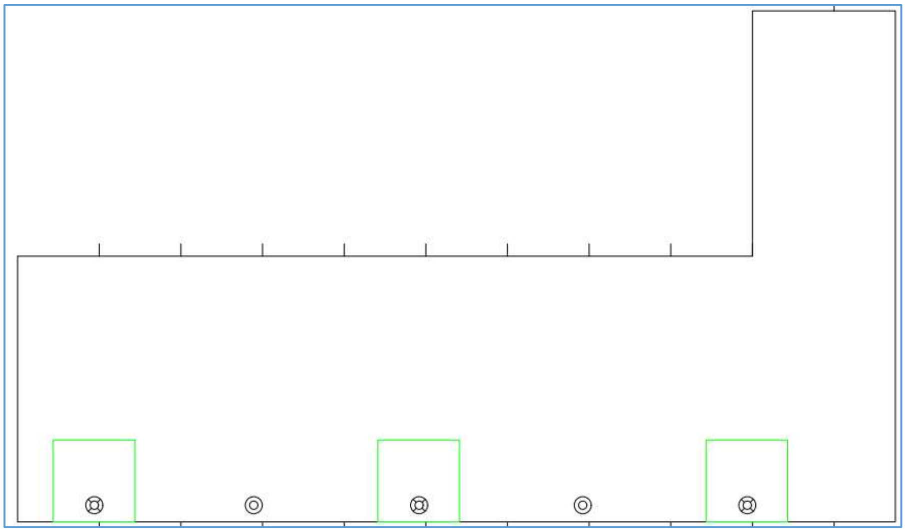


Figure 156: The upper catwalk of Area 1 showing strobe placement and areas of coverage.

Mass Notification System Analysis

Reference (y), Section 24.5, "In-Building Mass Notification Systems," is not applicable to the ACME Building. Consideration of the cost/risk balance concludes that the high cost to retrofit a 1959 structure with a modern Reference (y) compliant Mass Notification System (MNS) is not justified. The existing PA system is sufficient to meet the needs of the occupants' response to emergency conditions based upon the general risks associated with the kind of work performed within this building and the training that the personnel receive. Other compensatory actions, such as the presence of armed security, site wide video monitoring, and an existing PA system make Reference (y) MNS compliance non-mandatory.

Some methods to obtain MNS compliance are not permissible in the sensitive research environment of the ACME Building. Radio Frequency (RF) communication that ties into a control center is not permissible due to security concerns. Additionally, copper-line communication redundancy and protection would not be cost-effective to upgrade to.

the ACME Building uses the BiAmp Vocia communications system. This equipment can support a Reference (y) compliant MNS; however, does not in our case due to cabling and monitoring issues. The networking side of this equipment does not meet the listing requirements for this equipment to be compatible with a Reference (y) MNS system. This PA system also does not have Reference (y) MNS required system status monitoring equipment.

The BiAmp's Vocia system uses VA8100c amplifiers. The ACME Building uses four of these amplifiers, which provides 16 independent communication zones throughout the building. The amplifiers have Uninterruptible Power Supply secondary power, which provides approximately 3.75 hours of emergency power usage. In addition to this emergency power, the building is supported by four Emergency Diesel Generators that provide secondary power within 60 seconds in the event of a power failure.

The PA system is also equipped with an Ethernet connection to all the cabinet equipment and to the core switches throughout the campus. This fulfills the dual-path MNS requirements for the Class N Network. Each of the 16 PA zones in the ACME Building includes an active zone monitoring device (End of Line Device [ELD]) that actively monitors the line for opens, shorts and ground faults. The ELD will generate a fault signal on the affected amplifier if one of the conditions is met. The ELD is not currently automatically monitored and relies on personnel to observe that a problem exists from a control screen, so it does not meet code requirements for MNS systems.

Each FACP cabinet throughout the campus also has a paging station installed which is capable of being used as a local broadcasting station. Each zone can be selected individually or the whole the ACME Building can be selected. The BiAmps Vocia system comes with an MS1e control module that serves to control all system functions including playing messages automatically based upon program requirements. There is one of these installed at the ACME Building but other cabinets within adjacent buildings have these control modules installed. This provides a decentralized system in that if any one of these control modules fails, its functions will automatically be transferred to a functioning MS1e in the other cabinets providing a resilient control scheme.

Secondary Power Supply Calculations and Evaluation

Areas 1 and 2 of the first floor as shown in Figure 147 and Area 1 of the second floor as shown in Figure 148 are a subset of the overall FAS protecting the ACME Building. FASP/FATP #36 is in Area 2 of the first floor and is shown on the south wall in Figure 150. This FASP/FATP covers other areas within this building. This section analyzes the respective battery calculations for the entire area covered by FASP/FATP #36.

An estimate for the components for FASP/FATP #36 and the initiating and annunciating devices connected to this FASP/FATP are shown in Table 19 below. Any ELDs for annunciators are represented in the current being drawn for the cabinet components shown below.

A minimum battery size of 88.1 Amp-hours is required to be compliant with the requirements of Reference (y). The sealed lead-acid battery that is supplied at this location provides 100 Amp-hours, so is conservative for the system requirements.

Inspection, Testing, and Maintenance

the ACME Building utilizes the FAEDC for monitoring signals. The IT&M for the FAEDC is subcontracted to another entity. This section will not cover those IT&M requirements but will focus on the requirements for the ACME Building and the main FACP in Room 102b in PNNRA-603.

The personnel conducting the IT&M for the FAS at the ACME Building have qualifications deemed appropriate by the contractor FCO. These individuals perform the applicable IT&M as required by Reference (y).

Testing requirements include initial acceptance testing and testing when the system is modified or upgraded. These requirements are enumerated within Chapter 14 of Reference (y).

Table 19: FASP/FATP #36 battery calculations.

Description	COMPONENT	Manufacturer	QUANTITY	STANDBY CURRENT (AMPS)	ALARM CURRENT (AMPS)	TOTAL STANDBY CURRENT	TOTAL ALARM CURRENT
Control Panel Components							
MULTI-MODE FIBER OPTIC INTERFACE	D2300 CPS	Siemens	1	0.066	0.066	0.066	0.066
DIGITAL AUDIO CARD	DAC-NET	Siemens	1	0.23	0.23	0.23	0.23
INTERFACE FOR DNET	DFM	Siemens	1	0.135	0.135	0.135	0.135
INTELLIGENT CONTROL POINT DEVICE	HCP	Siemens	3	0.03	0.252	0.09	0.756
LOCAL PAGE BOARD	LPB	Siemens	1	0.05	0.13	0.05	0.13
LIVE VOICE MODULE	LVM	Siemens	1	0.04	0.04	0.04	0.04
NETWORK INTERFACE CARD	NIC-C	Siemens	1	0.12	0.12	0.12	0.12
SYSTEM PERSON MACHINE INTERFACE	PMI	Siemens	1	0.23	0.23	0.23	0.23
4 ZONE INDICATING CARD	ZIC-4A	Siemens	2	0.089	0.089	0.178	0.178
4 ZONE INDICATING CARD	ZIC-4A	Siemens	5	0	0.034	0	0.17
DEVICE LOOP CARD	DLC	Siemens	2	0.145	0.1	0.29	0.2
ZONE AMPLIFIER MODULE	ZAM-180	Siemens	2	0.3	0.3	0.6	0.6
POWER SUPPLY / CHARGER (active relay addition)	PSC-12	Siemens	2	0.02	0.02	0.04	0.04
POWER SUPPLY / CHARGER	PSC-12	Siemens	1	0.15	0.15	0.15	0.15
12 AMP POWER SUPPLY EXTENDER	PSX-12	Siemens	1	0.15	0.15	0.15	0.15
REMOTE ANNUNCIATOR WITH CONTROL	SSD-C-REM	Siemens	1	0.2	0.2	0.2	0.2
Initiating and Annunciating Devices							
INITIATING DEVICES ON DLC							
MANUAL PULL STATIONS	HMS-M	SIEMENS	23	0.0015	0.0015	0.0345	0.0345
PHOTOELECTRIC SMOKE DETECTORS	HFP-11	SIEMENS	8	0.0018	0.0018	0.0144	0.0144
ADDRESSIBLE INTERFACE MODULES (misc. devices)	HTRI-S	SIEMENS	18	0.0013	0.0013	0.0234	0.0234
ANNUNCIATING DEVICES on ZAM-180 (via ZIC-4A)							
WALL MOUNT SPEAKERS	SEH-4	SIEMENS	135	0	0.0625	0	8.4375
WALL MOUNT STROBES	ST-75-R-WP	SIEMENS	123	0	0.175	0	21.525
WALL MOUNT HORN STROBE	SZ-MC-R	SIEMENS	6	0	0.188	0	1.128
WALL MOUNTED SPEAKER STROBES	SEH-MC-R	SIEMENS	23	0	0.2375	0	5.4625
					Totals:	2.6413	40.0203
					Description	Quantity	Units
					Standby Time:	24	Hours
					Alarm Time:	15	Minutes
					Oversize Factor:	20%	Percentage
					Total Amp-Hour Required	**88.1**	Amp-hours

Any maintenance resulting from problems identified during the inspection and testing process, or as required by the manufacturer, shall be performed using the manufacturer's instructions for the given item. Records for the IT&M results shall be kept until the next required IT&M and then at least one year after that. These records are maintained by the subcontracting personnel and are available through the fire alarm CSE. Additional requirements for record keeping are found within Reference (y) Chapter 14 for unique situations.

Despite the minor non-compliant conditions that were identified, compared to commercial industrial facilities of similar size, the fire risks within the industrial portions of the building are quite low. Additionally, the fire risks in the office and storage areas are less than what is typical in general industry. These risks are further moderated in the industrial areas by the very high ceilings and largely non-combustible processes and process equipment.

There are also extensive procedural and administrative controls to minimize combustible loading and ignition sources. The fact that the ACME Building is actively monitored and routinely inspected by watch standers provides additional protection against the potential for situations that could create a fire.

GENERAL OPERATIONAL REQUIREMENTS FOR FIRE SAFETY

Fire Extinguishers

Fire extinguishers are placed correctly in accordance with Section 906 of Reference (a). Preventative Maintenance programs are in place to ensure compliance is maintained in accordance with the 2018 NFPA 10, Reference (z), standard regarding inspections and maintenance.

Fire Service Access

Fire apparatus road access is maintained in accordance with Reference (a). These routes ensure full access by fire apparatus to the outside perimeter of the building within 150-feet of all locations. These routes are maintained through required Fire Marshal inspections that occur weekly.

Manual Firefighting Response

There are no standpipes within this structure. Manual firefighting operations are the responsibility of the PNNRA Fire Department and have not been delegated to an on-site brigade. The equipment owned and maintained by this fire department meets the objectives defined by the Baseline Needs Assessment, Reference (aa), for this facility. Reference (aa) was most recently updated in March 2021 and will be updated again in 2024. Response actions at the building are directed by the Pre-Incident Plan that is developed by the fire department. Direction and coordination for emergency actions are directed through the Incident Command Post as defined in the Integrated Emergency Response and Contingency Plan, PNNRA-1013, Reference (bb), for this facility. Firefighting water supplies are available from nine fire hydrants all located within 400’ from the building around its perimeter. Any one of these hydrants can supply up to 2,000 GPM.

[redacted]

Figure 157: First floor of the ACME Building showing adjacent fire hydrants.

Emergency Evacuation

The evacuation routes utilize existing MOE paths to reach exit doors from within the building. A wide (60') public way surrounds most of this building. Exit Discharge paths are sized appropriately. The evacuation routes follow the public way to the PNNRA-692 cafeteria in the adjacent building, which is the designated muster location for this building. Maps of evacuation routes and required actions expected for personnel are included within the Reference (bb).

Building occupants are responsible for promptly evacuating during a fire alarm and reporting to the muster location. Any anomalous conditions shall be reported to management.

Managers are responsible for:

1) Awareness of occupants who may have disabilities which could delay evacuation.
2) Warning others during an evacuation and ensuring personnel are evacuating promptly.
3) Reporting to the muster location and coordinating with other managers to provide information to the Incident Commander.
4) Managers shall account for their personnel.

Exposures to the ACME Building

The exterior exposure concerns are defined as buildings that are under 60-feet from the ACME Building. PNNRA-636 has the highest combustible loading of the buildings adjacent to the ACME Building. PNNRA-636 is approximatley 41-feet to the south of PNNRA-117 and represents the most significant danger regarding exposure fires. The gap between these buildings, the non-combustible construction in this area, and the nature of the combustibles stored in PNNRA-117 and PNNRA-636 results in a safe configuration where fire spread between the two buildings is very unlikely.

Fire Evacuation Plan

The emergency procedures for this building are within Reference (bb) that is maintained by the Emergency Planning group that supports this site.

Fire Drills

Fire Evacuation drills are performed for this building in accordance with Section 405 of Reference (a) and shall occur at least annually. These requirements are found outlined within the site's Fire Protection Manual, PNNRA-1575, Reference (cc). This manual includes the expectations for drills and any reports associated with such drills. Emergency response actions during drills follow the prescriptive requirements within Reference (bb) for actions associated with fire alarms.

Personnel shall receive annual Computer Based Training that is approved by the Fire Code Official regarding required actions during fire evacuation events. This training shall include the following:

1) Actions for reporting fires as defined in Reference (bb).
2) The Muster location and routes to it as defined in Reference (bb).
3) Actions for accountability as defined in Reference (bb).

Pre-Incident Plans

At a three-year minimum periodicity, the pre-incident plans used by the fire department for firefighting for the building shall be reviewed and concurred to by the fire department regarding actions associated with emergency responses that are expected to be performed.

General Requirements

General production operations shall follow the requirements within Reference (cc). This includes, but is not limited to:

1) Hot work shall follow the requirements contained within the site's Hot Work Procedure. Any hot work activities shall require a hot work permit issued by the Fire Marshal or designee.
2) Hazardous Material (HAZMAT) as defined in Chapter 50 of Reference (a) shall be managed appropriately to keep quantities under the Maximum Allowable Quantities (MAQ) permitted by code. HAZMAT storage locations shall be inspected quarterly by the Fire Marshal or designee. New chemical additions to such a location shall be pre-approved by the Fire Marshal. An independent inventory shall be performed two times each year to verify quantities. The Fire Marshal shall confirm twice yearly that the MAQ limits are not violated.
3) Placarding per NFPA 704 is required for any HAZMAT quantities above the limits identified in Section 105.6 of Reference (a).
4) Combustible loading shall be limited to levels required for operations. Combustible waste shall be promptly removed by the end of shift. Staging of combustibles required for operations within a work area shall be limited to that which is required for a 24-hour window only, unless approved by the FCO or Fire Marshal.
5) Combustible materials shall not be stored in the following locations:
    a. Electrical or mechanical rooms except for materials used within those rooms (i.e. filters, parts, and tools) where the materials are stored in a metal job box or as approved by the Fire Code Official.
    b. Enclosed stairways, exit enclosures, or exit passageways.
    c. Where prohibited by a facility Fire Hazard Analysis.
6) Personnel shall receive initial training regarding the employee responsibilities found within Reference (cc).
7) Any new equipment, changes to occupancy-use of the building, and any new construction related activities that affect the building shall receive prior approval from the FCO or the Building Code Committee.
8) Smoking is prohibited within this building. Smoking is only permitted outside at designated smoking locations.
9) The employee-owned small appliances are permitted to be used within employee work areas as outlined in Reference (cc).
10) Portable Electric Heaters shall be limited to those outlined within Reference (cc). Exceptions can be made with approval from the Fire Code Official.

Operations Personnel Shall Have the Following Training:

1) Personnel who are expected to respond and combat an incipient fire shall be required to obtain fire extinguisher education and training. Operations management shall designate these individuals and provide the list to the training organization.
2) Personnel who are required to perform hot work fire watch duties shall have fire watch and fire extinguisher training. Operations management shall designate these individuals and provide the list to the training organization.

Ladder Use

Ladders that are used as the sole method of access and egress for an equipment platform shall comply with 29CFR1910, Reference (dd), Subpart D 1910.27. Access to an equipment platform that is by a single ladder shall be limited to a total occupancy of three persons.

Wildland Fire Season Precautions

the ACME Building is within the Wildland Urban Interface. Stage I wildland fire restrictions are implemented based upon temperature and general atmospheric conditions. These restrictions usually are effective May 1st to October 31st unless otherwise directed by the Fire Code Official. The required precautions are as follows:

1) No unprotected outdoor combustible storage is allowed within 10-feet of the exterior of the building.
2) All unscreened doors and windows shall be shut during off-shift hours.
3) A 30-foot defensible mowed area shall be established around the building.
4) Remove all combustible trash and vegetative accumulations from within 10-feet from the exterior of the building.
5) Ensure all trees are pruned back away from the building by at least 10-feet.
6) Ensure the roof is cleared from all accumulations of vegetation debris such as leaves and pine needles.

RISK ASSESSMENT APPROACH FOR FIRE SAFETY

Calculating the Likelihood of an Uncontrolled Fire

This section of the report reviews the expected statistical performance of the facility in a fire event. The event tree shown in Figure 158 calculates expected life safety features performance that includes all aspects of suppression and control of fires. Those aspects include personnel using fire extinguishers, manual firefighting efforts, automatic suppression, and general detection. The yellow highlighted results show the expected failure of these life safety systems that will result in fires growing and not being adequately controlled. Summing these yellow highlighted rows results in a 0.2% probability for a fire not to be controlled by our existing systems, including the local fire department. The probabilities used as inputs for this event tree are generally accepted by industry. This 0.2% probability likely represents a higher value than expected due to the low combustible loading of this facility that results in a high likelihood of burnout without resulting in extensive fire spread and building failure, so this 0.2% value is very conservative. What this translates to is an approximate 1 in 500 fires that occur within this facility that will result in serious fire spread within this facility that results in partial building collapse.

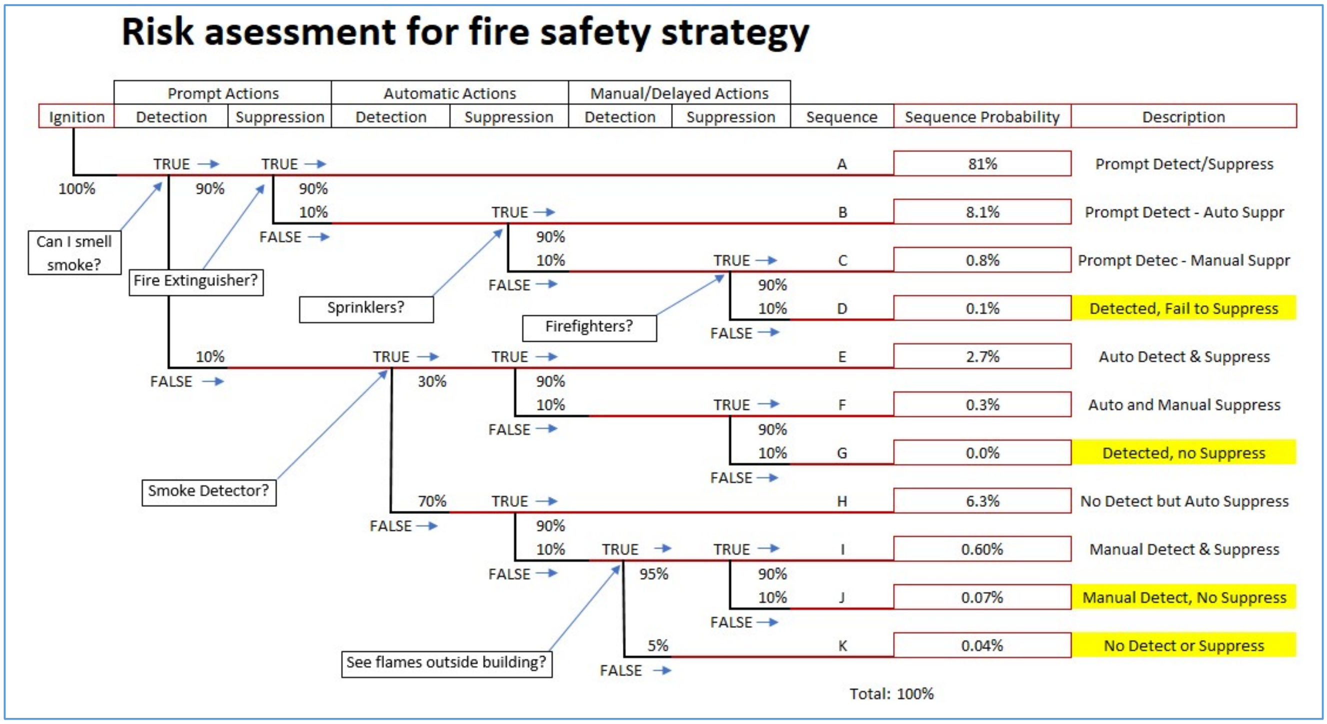


Figure 158: Detection and suppression event tree for control of fires in the ACME Building.

Calculating the Likelihood of a Fire Based upon Historical Data

The SEC is required to provide a publicly available annual report of expenses associated with fire related damage and the costs associated with fire protection support programs including IT&M. The published SEC Annual Fire Protection Program summaries for 2011-2020 inclusive have been analyzed for this FHA. This analysis shows that an average of 28.3 structural fires per year occur throughout the United States SEC complex. The average annual structural fire losses for this period in 2022 dollars is an aggregate total of $1,070,000. This number does not reflect other fire related costs, such as wildland fires, hazardous material related spills, and incidental medical responses. Only the data associated with actual structural fires will be analyzed here.

The estimated full value of the entire SEC complex in 2022 US Dollars is approximately $263 Billion. The calculated average SEC annual losses for structural damage as a percentage of overall SEC complex value is approximately 0.0004%. The annual probability of a fire breaking out in the ACME Building is on the order 0.3% based upon the number of buildings in the SEC national complex and the average number of buildings that have a fire within them each year.

The estimated annual risk associated with a fire in the ACME Building that burns out-of-control and results in partial building collapse is as follows:

$$0.3\% * 0.2\% = 6E\text{-}6$$

This is an extremely low risk and below the accepted 1E-5 annual risk specified within the SFPE Guide to Fire Risk Assessment, Reference (ee). This risk is based upon the 0.3% fire occurrence frequency due to the effort the SEC has placed in fire minimization. Every effort should be continued to maintain a small level of frequency for a fire to occur within the ACME Building. Figure 159 shows a generic relationship between cost and risk improvements. Initial efforts to minimize fire frequency have included combustible minimization and control over ignition sources. This represents low-cost efforts that produce significant gains in fire safety in comparison with high-cost efforts that produce minimal gains. This figure will be discussed in the conclusions.

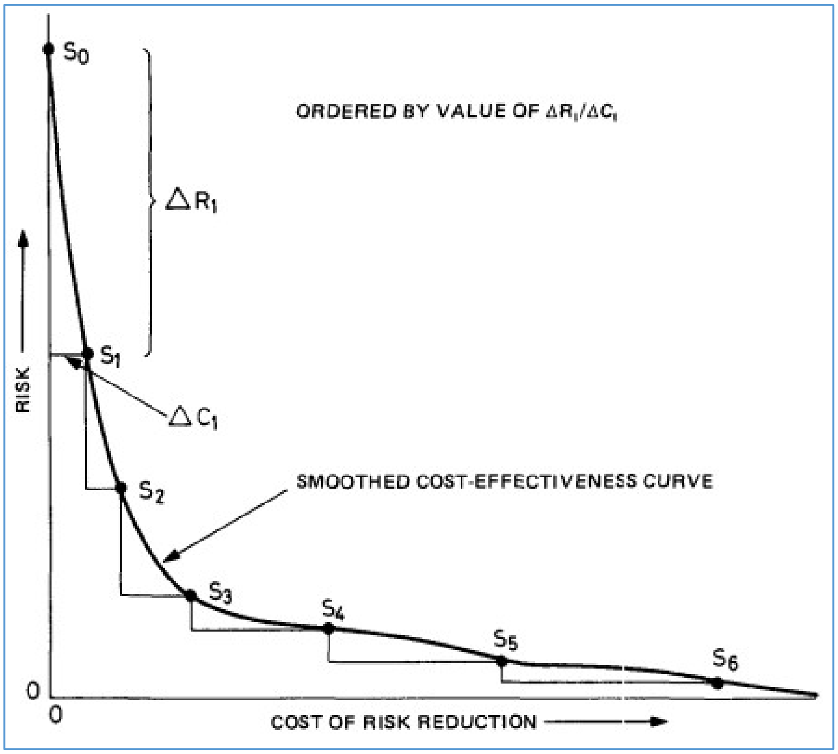


Figure 159: Graph showing increasing cost for risk minimization for a project.

MAXIMUM POSSIBLE FIRE LOSS (MPFL) AND MAXIMUM CREDIBLE FIRE LOSS (MCFL) CACLCUATIONS

Reference (ff) defines the MPFL as, "The value of property/contents within a fire area. This assumes the failure of both automatic fire suppression systems and manual firefighting efforts." MCFL is defined as, "The value of property within a fire area. This assumes both automatic fire suppression systems and manual firefighting efforts are effective." This section provides an engineered estimate for both the MPFL and MCFL costs.

MPFL

Figure 158 shows that there is an estimated 0.2% probability that fires in the ACME Building will not be controlled by the existing systems and processes. This section estimates the final costs where a fire is not controlled and spreads in a worst-case manner. This section does not take into consideration unusual and extreme events such as terrorism and implausible situations resulting from improperly controlled explosive materials or other highly unlikely scenarios.

PNNRA-PPP-02570, Reference (gg), specifies that general shutdowns associated with any fires at PNNRA will result in an approximate $3,900,000 cost due to work-pauses, retraining and investigations. An MPFL level event at the ACME Building will likely impact general operational needs for several years. These operational costs are not evaluated in this analysis, but it is reasonable to assume that the opportunity costs by not having the ACME Building available for operations likely translates to 10's of millions of dollars. A value of $15,000,000 will be applied for those losses.

The International Code Council (ICC) is the agency that produces the building and fire codes used by PNNRA. ICC publishes building valuation cost estimates based upon the type of construction. The ICC Building Valuation Data – February 2021, Reference (hh), specifies that Type IIB noncombustible construction used for a Group-B occupancy is $188/ft^2. The estimated price for Group-F1 Type IIB construction is $108/ft^2. The ICC construction costs shown above applied in 2021 and are applicable to general industry. These estimated costs are doubled for this analysis for any PNNRA-related work due to additional regulations, oversite, and the steep construction related inflation recently experienced. The final estimated construction costs are $216/ft^2 for industrial areas and $376/ft^2 for business areas.

The following MPFL worst-case fire is highly unlikely and a bounding example that is used for cost calculations only. An out-of-control fire would likely burn out because of the low fuel loading and non-combustible construction. The following event is highly improbable but provides a cost-baseline for this analysis. A worst-case fire at the ACME Building would occur in the DBF location identified as the Workstation Fire in the northeast office location on the first floor as shown in Figure 111. The existing combustile loading and the compartmentation geometry could result in flashover conditions. The lack of fire rated construction could result in fire spreading through the office and process areas on the 1st and 2nd floors on the north side of the building. This fire could spread through an 11,000 ft^2 area of the 2nd floor and structurally damage the east portions of the HCLA and fan room, and the north portions of the middle of the PNNRA-517 high bay. The first-floor fire spread could include all the office areas and some of the HCOG and supervisor offices on the north beach. The area for this fire could be 18,000 ft^2 and result in serious structural damage to the north portion of the PNNRA-517 high bay requiring replacement of the structural members on the north side of the building. The overall impacted 1st floor area will be approximately 30,000 ft^2 that will need to be replaced due to damage from the structural collapse of the north portion of the building. The liklihood of further spread is minimal due to the water pool to the south, the hot cells to the west and the high bay to the east that has minimal combustible loading. The following table shows a summary of MPFL related costs for construction:

Table 20: Estimated construction costs for MPFL fire.

	1st Floor	2nd Floor	Cost per ft^2	Cost
Group-B	8,000 ft^2	10,000 ft^2	$376	$6.8 Million
Group-F	22,000 ft^2	1,000 ft^2	$216	$5.0 Million
Total				**$11.8 Million**

The estimated equipment damage is estimated as equivalent to the structural costs. The total costs are itemized in the following table:

Table 21: MPFL Cost Summary.

Shutdowns and retraining	$3.9 Million
Operational Costs	$15 Million
Construction	$11.8 Million
Equipment	$11.8 Million
Total	**$42.5 Million**

Section 102.4 of Reference (ee) provides additional actions if the MPFL exceeds $150 Million. Given the $42.5 Million MPFL for the ACME Building, additional actions are not necessary.

MCFL

Figure 158 illustrates that in approximately 99.8% of fires within the ACME Building, the fire will be controlled and not result in substantial damage. This MCFL section identifies the worst-case controlled fire that may occur. Implausible scenarios are not considered in this section such as deliberate attempts to damage the fire safety systems. This investigation also ignores situations where extreme combustible loadings are deliberately placed within the ACME Building such as the storage of large quantities of non-permitted flammable liquids or substantial high-piled (>12 feet) combustible storage.

The worst-case MCFL will be the truck fire at the location shown in Figure 108. As discussed previously, this DBF could result in uncontrolled fire spread in the high bay, if this area continues to be used for storage. The fire will overpower the suppression system and could result in structural collapse depending on the quantity of the stored items in this area. This report previoulsy proved that a truck fire could result in fire spread to wood crates as far away as 13 m from the fire. If combustible crates are stored adjacent to the steel structural columns in the area, those ignited crates will weaken the structural columns resulting in possible collapse. A situation resulting in collapse is highly unlikely because of the nature of the combustibles stored here and the time required to expose these columns to a standard fire as shown in Figure 93, but will be used as a worst-case scenario. This will result in an approximate area of fire of 6,000 ft^2 as shown in Figure 160, and a likely impacted area requiring reconstruction of 10,000 ft^2. The area being impacted is because the suppression system will be overpowered resulting in minimal control of the fire until the fire department responds. Reference (aa) specifies an approximate fire department response time of just over 17 minutes. Combining the detection and signaling time gives a worst-case response time of approximately 20 minutes before the PNNRA firefighters will start offensive firefighting operations. It is not expected that the fire will impact more than the area shown in Figure 161. The fire rated construction to the south of the truck fire, and the non-combustible construction to the north and the minimal combustibles to the north and to the east will prevent the fire spreading prior to when the fire department arrives and controls the fire.

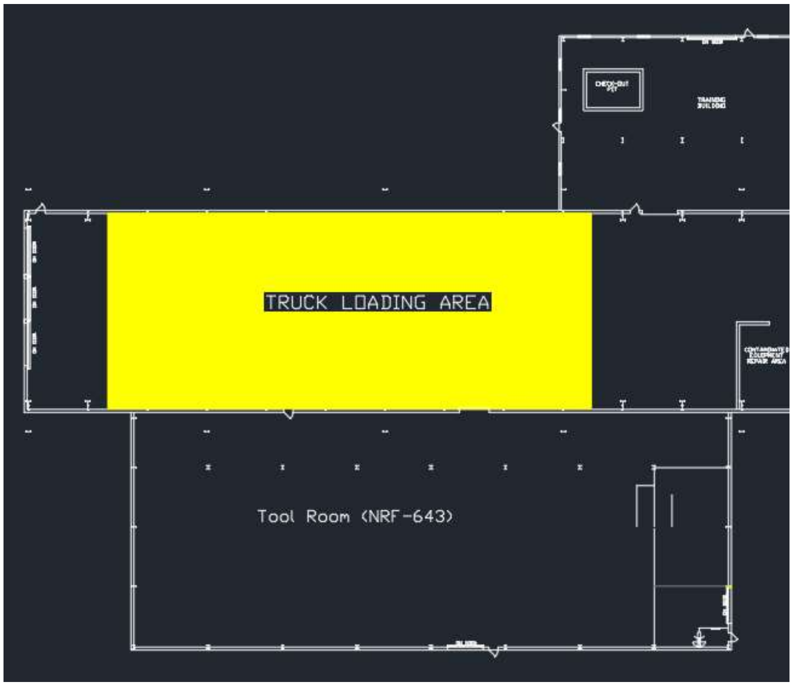


Figure 160: Estimated area directly affected by a truck fire. This location is shown in Figure 108.

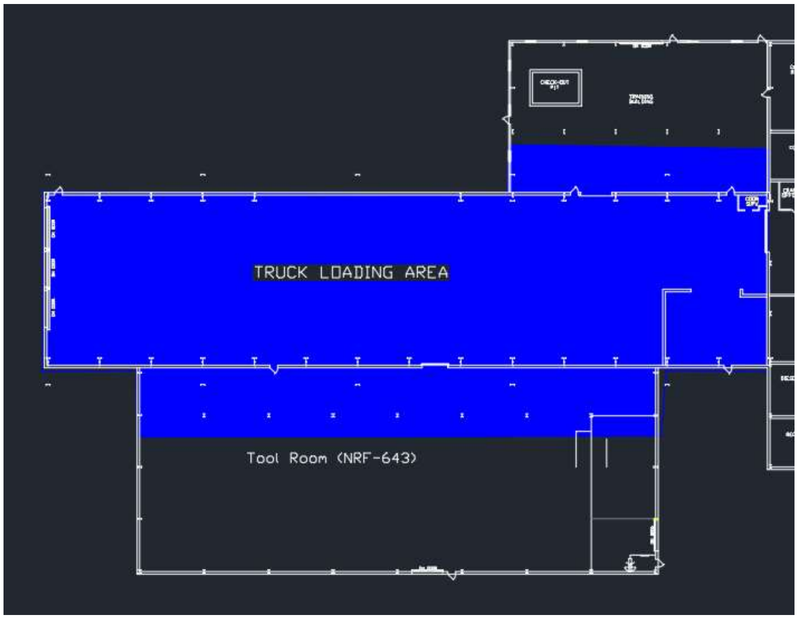


Figure 161: Estimated MCFL impact zone.

The operational costs are assumed to be about the same as the MPFL at $15 Million. The MCFL values are calculated using the same cost for construction as was used in the MPFL. The equipment costs are estimated at approximately equal to the construction costs. The area that is impacted is industrial, so has a $216/ft^2 replacement cost. The total reconstruction cost is as follows:

$$\$2.2\ Million = \frac{\$216}{ft^2} * 10{,}000\ ft^2$$

The total MCFL costs for the ACME Building are shown in Table 22 below. For both the MPFL and MCFL, there is sufficient margin in the operational impact value to make up for mistakes regarding construction costs.

Table 22: MCFL Cost Summary.

Shutdowns and retraining	$3.9 Million
Operational Impact	$15.0 Million
Construction	$2.2 Million
Equipment	$2.2 Million
Total	**$23.3 Million**

Reference (ee) does not give any additional actions for an MFCL of $23.3 Million, so additional actions are not necessary.

CONCLUSION

The prescriptive code analysis portion of this FHA demonstrates that the ACME Building meets current building and fire codes except for a few minor issues that are currently being resolved. The performance-based analysis portion of this FHA proved that personnel can safely egress even when the building is exposed to maximum expected fire scenarios. This analysis involved software modeling through both FDS and PathFinder to validate the accuracy of hand calculations to ensure the conclusions regarding safe egress of occupants were correct.

The suppression systems were examined and validated to be acceptable with one major exception. The main finding from the suppression analysis is that the sprinkler system in PNNRA-117, Riser 9, does not supply enough water to adequately protect the type of commodity in this location. It is also questionable whether a fire in PNNRA-117 will be sufficiently hot to initiate suppression, depending upon where the fire is and what the ceiling height is at the fire location. Riser 9 should have additional analyses performed on it to characterize its performance at a higher level of detail.

Design fires were selected to validate suppression system activation and occupant egress. These design fires included:

1) Pool fires from diesel and gasoline spills.
2) Workstation fires.
3) A truck and trailer vehicle fire.

The pool fires used included a peak HRR of approximately 25 MW. These pool fires that were modeled in a high bay area demonstrated that suppression would activate, and the smoke layer levels would be sufficiently high that occupants can safely egress.

The workstation fires that were modeled had a peak HRR of 1.6 MW, which is at the threshold for flashover conditions for the compartment analyzed. The results from FDS indicated that a flashover is not likely without additional fire spread resulting in a higher HRR for the typical compartments in this building. In the absence of suppression, it is likely that the fire will spread and will produce an HRR at a level where flashover will occur. FDS also showed that suppression will activate within compartments early in the fire growth and will likely control the fire spread to HRR levels that will not result in flashover conditions.

The workstation fire model applied in an open warehouse indicated that combustion will likely not spread if adjacent islands of combustible materials are kept approximately ten feet away from the workstation area.

The most significant finding is that the truck fire may or may not initiate suppression within the high bay location where the ceilings are about 60 feet above the floor. Even with suppression activation, the sprinklers will not control a truck fire. Such a fire will spread to adjacent combustibles resulting in a larger fire that could overpower the suppression system and lead to serious structural damage if combustibles are stored around support members. This is a primary reason to minimize combustible storage near the truck and trailer used for transporting materials in and out of the facility. The normal processes include using a truck within the west portion of the PNNRA-517 high bay.

The lack of fire rated construction is a serious limitation to the overall structural performance of this facility in a fire situation. Suppression provides the only method of protecting the facility. Policy actions such as minimizing combustibles and providing adequate separation between combustibles provide a passive layer of protection, but compartment fires will result in serious structural damage in the absence of suppression due to the lack of fire rated protection around structural members. This concern should be addressed in future construction by requiring fire rated structural members.

The fire alarm system is excellent and expected to perform its role in notifying occupants when activated. This is a manual system except for a limited number of automatic smoke detectors where required by code. Improved performance regarding detection time, particularly during periods where there are minimal people in this facility, can be achieved by placing more extensive automatic smoke detection capability in this facility. An automatic detection system is not required by the building or fire codes and would likely not be cost-justified for the added protection it could provide but is feasible if concerns arise for future processes introduced to this facility.

There is roughly a 1 in 500 chance that a fire, should one occur, overcome the existing fire protection systems, and become uncontrolled. This threat is tempered by the very low likelihood of a fire occurring, and the threat can be further lessened by enacting policy changes regarding how combustibles are managed. The following recommendations will assist in improving the likelihood of avoiding a fire in the ACME Building:

1) Minimize combustibles by utilizing six-sided steel cabinets for storing items. Cubicles can be purchased with steel shelves having doors that can be closed. NFPA has specified a combustible loading derating of 90% if six-sided metal cabinets are used.
2) Minimize ignition sources. Minimize the use of high-wattage personal electric heaters in favor of low-wattage systems at the desks of personnel.
3) Eliminate the use of wood pallets within the ACME Building.
4) Eliminate wood crating in favor of steel crating.
5) Minimize the threat of fire from stored combustible commodities within the Tool Room (PNNRA-117). Use an island approach to the storage of combustibles or utilize a wider separation between rows of storage. Use closable metal cabinets or steel crates.
6) Eliminate combustible materials from being stored near trucks within the building. Re-evaluate whether trucks are operationally necessary within the ACME Building.
7) Update the suppression system to include seismic restraints.
8) Remove the large and unused ceiling level door in the main ACME Building high bay that is blocking suppression heads. There is no reason to allows this door to remain in place.
9) Update the suppression system riser placards with the correct information.

The ACME Building is a safe structure as it is currently used. This analysis has demonstrated that personnel can safely egress even with a worst-case fire. The above recommendations will improve the fire safety strategy by minimizing the likelihood of an out-of-control fire and will provide an additional safety shield in the event suppression or manual firefighting operations are unavailable due to extreme situations. The findings within this report should also be considered regarding new facilities. Using suppression as a single point of failure for building and occupant safety is not appropriate for a facility whose operations could lead to serious consequences in a fire. The ACME Building is recommended for continued operational use; however, management is recommended to take actions as outlined in this report to maintain the goal of continual improvement for the building's fire-safety posture.

REFERENCES

Reference (a) 2018 International Fire Code
Reference (b) 2018 International Building Code
Reference (b.1) PNNR S6698, the ACME Building Servicing Manual
Reference (c) 2015 International Building Code
Reference (d) PNNRA-PPP-1017
Reference (e) PNNRA-PPP-00018
Reference (f) KEY-CES-00475
Reference (g) PDQ-78110-12-088
Reference (h) Society of Fire Protection Engineering Handbook of Fire Protection Engineering 5th edition
Reference (i) Improved Formulation of Travelling fires and Application to Concrete and Steel Structures, June 2015
Reference (j) Structural Design for Fire Safety, 2nd Edition
Reference (k) NFPA Fire Protection Handbook, 20th edition
Reference (l) SFPE Guide to Human Behavior in Fire, 2nd edition
Reference (m) 2018 Life Safety Code, NFPA 101
Reference (n) Experimental Study on the Fire-Spreading Characteristics and Heat Release Rates of Burning Vehicles Using a Large-Scale Calorimeter (www.mdpi.com)
Reference (o) An Introduction to Fire Dynamics, 3rd edition
Reference (p) University of Maryland’s Burning Item Database
Reference (q) National Institute of Standards and Technology Fire Calorimetry Database, “nist.gov.”
Reference (r) Professional Engineering Ref. Handbook for the Fire Protection Engineering exam, V1.0
Reference (s) 2019 NFPA 72
Reference (t) 2019 NFPA 13
Reference (u) 2016 NFPA 13
Reference (v) 1969 NFPA 13
Reference (w) 2017 NFPA 25
Reference (x) 2010 NFPA 72
Reference (y) 2016 NFPA 72
Reference (z) 2018 NFPA 10
Reference (aa) Baseline Needs Assessment
Reference (bb) Integrated Emergency Response and Contingency Plan, PNNRA-1013
Reference (cc) Fire Protection Manual, PNNRA-1575
Reference (dd) 29CFR1910
Reference (ee) Society of Fire Protection Engineering Guide to Fire Risk Assessment
Reference (ff) PNNR S6678, Building Code Manual
Reference (gg) PNNRA-PPP-02570, Risk Approach Determination for Trailer Suppression
Reference (hh) ICC Building Valuation Data – February 2021

APPENDICES

Appendix A: Combustible Materials Control Agreement

Appendix B: Available Cut-sheets for the Suppression System

Appendix C: Partial List of Cut-sheets for the Fire Alarm System

Appendix A: Combustible Materials Control Agreement

This appendix contains the minimum combustible loading expectations for the ACME Building. This information was taken from the historical agreements and has additions where information was lacking. The tables in this appendix do not reflect the recommendations included in this report. Those recommendations contained in the conclusion of this report should be evaluated and implemented where practical.

PNNRA-517 High Bay Combustible Controls

Building Area	Process or Operations Equipment	Combustible Materials Storage/ Use
West end of High Bay (including doors 4, 5, 6 and 59)	• Receipt/Shipment of Waste Materials • Load Testing/ Inspection of Rigging Gear • Equipment laydown	• Fuel spill control pans and 100-pound carbon dioxide extinguishers are stored adjacent to vehicle parking areas.
55 Ton Cask Maintenance area	• Maintenance and Load test of 55 Ton Cask	• Contamination control activities / materials (including Anti-Cs, poly bags, sheets, rubber gloves, poly bottles and PVC).
Quality Assurance/ Non-Destructive Test Area	• Inspection of Rigging Gear and Lifting and Handling Equipment	• Combustible materials limited to only items supporting ongoing work.
Decontamination Shop # 1	• Facility Caretaking	• Contamination control materials.
Equipment Pit #1, 2 and 3	• Equipment Removal and Stabilization	• Combustible products within cabinets designated for facility process functions to the maximum extent practicable.
The ACME Building water pool Controlled Surface Contamination Area	• Contamination Control Activities / Materials	• Combustible products within cabinets designated for facility process functions to the maximum extent practicable.
The ACME Building water pool beach area	• Equipment Operation and Staging	• Combustible storage within enclosed cabinets to the maximum extent practicable.
Observation Rooms	• Facility Caretaking	• Combustible storage within enclosed cabinets to the maximum extent practicable.
East end of High Bay (including doors 29, 30, 31 and 34)	• Equipment Laydown and Operational Checkout • Receipt/Shipment of New Equipment	• Combustible storage must be within enclosed cabinets to the maximum extent practicable.
Defueling and Maintenance Station	• Defueling/ Maintenance of Fuel Transfer Containers	• Combustible storage must be within enclosed cabinets to the maximum extent practicable.
Sailmaker's Shop	• Contamination Control Materials	• Minimize out of storage material.
Modesty Booth Anti-C Dressing area	• Contamination Control Materials	• Combustible products within cabinets designated for facility process functions to the maximum extent practicable.

PNNRA-517 High Bay Combustible Controls *Continued*

Building Area	Process or Operations Equipment	Combustible Materials Storage/ Use
Door 52 Waste Processing area	• Sorting of Packaged Material • Contamination Control Materials	• Laundered clothing stored in metal containers. Used clothing and waste is sorted and stored in metal containers to the maximum extent practicable.
Overhead Cranes and water pool work platforms	• Facility Support	• Oil Filled gearboxes, Greased bearings. • No combustible storage allowed.
DMS Fan Room	• Essential Facility Functions (Including Ventilation and HEPA Filter Equipment)	• No combustible storage allowed. • Greased Bearing / Fan Belts.
Enclosed offices within High Bay	• None	• General office equipment and files consistent with the purpose of workspaces.
MERS area	• Subcontract Storage Area (Including Scaffolding, Ladders) • Contamination Control Materials • Pipefitter Equipment	• Combustible products within cabinets designated for facility process functions to the maximum extent practicable.
Vehicle Storage	• Occasional Vehicle Use is Required to Meet Operational Requirements.	Vehicles in the high bay are limited to: • 55-ton Scrap cask tractor / trailer • NR / TRC cask tractor / trailer • NRBK trailer All other fuel powered vehicles, such as forklifts, are only permitted to perform the necessary task. No Motor equipment is allowed to be stored inside the high bay without FCO approval. Other vehicles may be permitted, but only with FCO approval.
Follow the requirements specified in PNNRA-1901, “Control of Operations Manual.”		

PNNRA 517 Administration and Office Area Combustible Controls

Building Area	Process or Operations Equipment	Combustible Materials Storage/ Use
General, applies to all office spaces	• None	• General office equipment and files consistent with the purpose of workspaces.
Conference and Meeting Rooms	• None	• Tables, chairs, video conference equipment, lights, and backdrops consistent with the room's function. • Files and office supplies.
Restrooms	• None	• Combustible janitorial products within cabinets designated for facility housekeeping functions.
Telecommunications Rooms	• Building Functionality	• No combustible storage allowed except for a minimal number of items such as applicable replacement parts.
Interior stairways	• None	• No combustible storage allowed.
Employee Breakrooms	• Food preparation • Personnel lockers	• Listed appliances that comply with Reference (cc). • Personal employee items in lockers. • Small quantities of typical office materials stored in metal cabinets to the maximum extent practicable.
Locker rooms	• None	• Clean and soiled laundry. • Minimize combustible storage.
Equipment Rooms 3 and 4	• Building Functionality	• No combustible storage.

PNNRA-517 Hot Cell Area Combustible Controls

Building Area	Process or Operations Equipment	Combustible Materials Storage/ Use
Loading Area (Including Manipulator Repair Shop)	• Repair and Movement of Manipulators • Equipment Laydown • Contamination Control Activities / Materials • Manipulator Operation and Replacement	• Combustible storage must be within enclosed cabinets to the maximum extent practicable.
HCOG (Including Enclosed Offices and Electrician Shop)	• None	• Combustible storage must be within enclosed cabinets to the maximum extent practicable. • General office equipment and files consistent with the purpose of workspaces.
Fan Room and HCOG Roof Area	• None	• Combustible janitorial products within cabinets designated for facility housekeeping functions.
The ACME Building HCOG	• Building Functionality	• No combustible storage allowed except for a minimal number of items such as applicable replacement parts.
Chemistry Wing	• Equipment Removal and Stabilization	• No combustible storage allowed.
Follow the requirements specified in PNNRA-1901, “Control of Operations Manual.”		

PNNRA 517/438 the ACME Building SFPF Combustible Controls

Building Area	Process or Operations Equipment	Combustible Materials Storage/ Use
SFPF South High Bay (Excluding Elevator Pit)	• Receipt/Shipment of materials • Rigging gear Storage • Equipment laydown • SFC / Overpack loading operations • Contamination control Activities / Materials (including Anti-Cs, poly bags, sheets, rubber gloves, poly bottles and PVC).	• Fuel spill control pans and100-pound carbon dioxide extinguishers are stored adjacent to vehicle parking areas. • Combustible storage must be within enclosed cabinets or limited to materials items supporting ongoing work to the maximum extent practicable.
Elevator Pits North and South (Including Cask Elevators)	• Material Movement	• In-use grease and oil. • Combustible storage must be within enclosed cabinets or limited to materials supporting ongoing work to the maximum extent practicable.
Overhead Cranes	• Facility support	• Oil filled gearbox, Greased bearings.
Transporter	• Material movement • Contamination control Activities / Materials	• Hydraulic lift system, Oil filled gearboxes and Greased bearings • Combustible products within cabinets designated for facility process functions or limited to materials items supporting ongoing work.
SFPF North (excluding elevator pit)	• Rigging gear Storage • Equipment laydown • Equipment laydown • SFC / Overpack loading operations • Contamination control Activities / Materials	• Combustible storage must be within enclosed cabinets or limited to materials items supporting ongoing work.
SFPF North Roof area	• Equipment Storage	• No combustible storage allowed.
Enclosed offices outside High Bay	• None	• General office equipment and files consistent with the purpose of workspaces.
SFPF Fan Room	• Essential Facility Functions (including Ventilation and HEPA filter equipment)	• Greased Bearings / Fan Belts. • Combustible products within cabinets designated for facility process functions.
Follow the requirements specified in PNNRA-1901, “Control of Operations Manual.”		

PNNRA-878 (Training and Equipment Checkout Station) Combustible Controls

Building Area	Process or Operations Equipment	Combustible Materials Storage/ Use
All of PNNRA-878	• Storage of Processing Materials Including Plastic Sheets. • Staging Items for Equipment Checkout, Typically in Wood Crates. Crates are Removed upon Completion of Use. • Storage and Use of Chemicals for Machining.	• Open rack storage with grated shelving. • Temporary storage of machine shop equipment and parts. • Combustible storage cabinets. • Flammable storage cabinets. • Storage of drums of mineral oil staged for ongoing maintenance of HCOG windows. • Miscellaneous office supply storage for use in the area.

PNNRA-878 (Tool Room) Combustible Controls

Building Area	Process or Operations Equipment	Combustible Materials Storage/ Use
All of PNNRA-117	• General storage.	• Minimize combustible storage to a reasonable level. • Use islands of storage or rows of storage with reasonable separation distances between them. • No storage shall exceed 12-feet in height. • Minimize the accumulation of combustible waste. This includes the staging of waste items that are waiting for characterization before being discarded.

Appendix B: List of Technical Cut-sheets for the Suppression System

This appendix contains technical details of some of the piping and riser components for System 3 that is not explained within the Suppression section of the FHA. The riser is shown in Figure 128.

Cut sheets deleted from this version due to security concerns.

Appendix C: Partial List of Cut-sheets for the Fire Alarm System

This appendix contains technical details of some of the fire alarm system components. These cut-sheets were used to provide power requirements shown in Table 19 to validate that this system is acceptable.

Cut sheets deleted from this version due to security concerns.