Fire Protection Engineering Analysis
For Building 910 - Sandia National Labs/CA
Livermore, CA
BY: Mo Mosallaei, P.E., CBO
Project Overview

- Concrete Structure – 3 story with a basement
- Basement houses boiler room, server rooms, communication centers
- First floor houses offices
- 2nd & 3rd floors house offices and laboratories
- Original Code of Record is the 1985 Uniform Building Code (built in 1988)
Current Photo
Applicable Codes & Standards

DOE Order 420.1.B utilizes the local Building and Fire Code regulations with some adjustments.

Applicable Codes and Standards:

- 2013 California Building Code (CBC)
- 2013 NFPA 13 – Standard for installation of Sprinkler Systems
- 2015 NFPA 12A – Standard on Halon 1301 Fire Extinguishing Systems
- 2013 NFPA 14 – Standard for the Installation of Standpipe and Hose Systems
- 2014 NFPA 25 – Standard for the ITM of Water-Based Fire Protection Systems
Prescriptive Code Information:

CBC Code Information for Building 910


Occupancy: B/L (Non-separated Mixed use)

Type of Construction: IIB

Open perimeter around the entire building for at least 80 feet in all directions.

Fully Sprinklered

Number of stories: 3 with a basement
Base Allowable Area and height per story per Table 503:
Group B: 23,000 ft² / 3 stories
Group L: 17,500 ft² / 3 stories
The entire building must meet the height/area limitations for group L.

Actual area per story: 14,600 ft²

Occupant Load Factor:
Office/Business areas: 100 (gross)
Laboratory areas (Non-educational): 100 (Net)

Occupant Load: 146 persons per floor
Structural Fire Protection

Calculating Fire Resistance ➔ The following details are extracted from the plans for Building 910.
Structural fire resistance properties

\[ t + \left( \frac{4t - 1}{s} \right) \left( t_e - t \right) \]

(Equation 7-5)

\[ s = \text{Spacing of ribs or undulations.} \]
\[ t = \text{Minimum thickness.} \]
\[ t_e = \text{Equivalent thickness of the slab calculated} \]

Thickness = \[ t + \left[ \frac{4t}{s} - 1 \right] \left( t_e - t \right) = 5.5\text{inches} + \left[ \frac{4(5.5\text{ inches})}{24\text{ inches}} \right] \left[ 10 - 5.5 \right] = 9.6\text{ inches} \]

**TABLE 721.2.2.1 MINIMUM SLAB THICKNESS (inches)**

<table>
<thead>
<tr>
<th>CONCRETE TYPE</th>
<th>FIRE-RESISTANCE RATING (hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Siliceous</td>
<td>3.5</td>
</tr>
<tr>
<td>Carbonate</td>
<td>3.2</td>
</tr>
<tr>
<td>Sand-lightweight</td>
<td>2.7</td>
</tr>
<tr>
<td>Lightweight</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Per Table 721.2.2.1, the equivalent fire resistance rating for the slab is **4-hours**
Using a similar process for walls the fire resistance for walls is calculated at **2-hours**
Sprinkler System

Hazard Classification: Ordinary Hazard, Group 2
Design Density = 0.20  Area of Calculation = 1500 ft²

\[ A_s = 100 \text{ ft}^2 \quad \text{Number of sprinklers Calculated} = \frac{\text{Design Area}}{\text{Area per sprinkler}} = \frac{1500}{100} = 15 \]

No. of sprinklers on a branch line = \[ \frac{1.2\sqrt{A}}{S} = \frac{1.2\sqrt{1500}}{10} = 5 \] sprinklers.
Sprinklers are ½ inch, RASCO brand with a K factor of 5.6
System Demand at riser: 51 psi at 609 gpm.

The sprinklers in the basement at located at only 6’ 8”.
They are protected with a cover for both the sprinklers protection and occupants.

System Demand at riser: 51 psi at 609 gpm.
Hose Stream = 500 gpm

Water supply available: 68 Psi Static, 63 Psi
Residual @ 2750 GPM
Hydraulic Graph

![Graph showing pressure vs. flow with Supply and Demand + Hose Stream lines]
Halon System

- Located in the communication Center in basement (3,000 ft²)
- In addition to the building’s wet pipe sprinklers.
- Considered an occupied space.
- Triggered by smoke detection system and a manual discharge pull station.
Halon System and Calculations

Calculating the volume: Ceiling Height = 10 ft. Underfloor depth= 4 ft.

\[ V = 14 \text{ ft.} \times 3,000 \text{ ft}^2 = 42,000 \text{ ft}^3 \]

Halon Quantity for total flooding:

\[
W = \frac{V}{s} \left( \frac{C}{100 - C} \right) = \frac{42000 \text{ ft}^3}{2.2062 + 0.005046(500)} \left( \frac{7}{100 - 7} \right) = 669 \text{ lbs.}
\]

Where \( W = \) Weight of halon, 
\( s = 2.2062 + 0.005046t, \) \( t = \) minimum anticipated temperature of the protected volume (\(^\circ\)F), 
\( V = \) net volume of hazard \( \text{ft}^3, \) \( C = \) Halon 1301 concentration, percent by volume = 7%

Add 20% minimum safety factor \( \rightarrow \)

Total quantity required = 803 lbs.
Quantity Provided = 988 lbs.
Halon System Safety Analysis

• Actual Concentration (based on available quantity) = 8.48%
• Lowest Observed Adverse Effects Level (LOAEL) concerns Per 2015 NFPA 12A Section D.1 is due to exposure to decomposing Halon after contact with Fire or hot surfaces.
• Maximum recommended exposure times based on concentration:
  7% and below = 15 minutes
  7 to 10 percent = 1 minute
  10 to 15 percent = 30 seconds
Other Halon hazards in addition to toxicity include:
• Noise – Often associated with loud discharges
• Turbulence – High velocity discharge may cause injuries with direct contact
• Cold Temperatures – Direct contact with vaporizing liquid can lead to frostbite burns
Fire Alarm System

(Throughout the building)

- **Means of Activation:**
  - Pull stations at exits
  - Area smoke detectors
  - Duct smoke detectors
  - Gas detection systems

- **Means of Notification:**
  - Horns & strobes
  - FACP signals
  - DACT monitoring system
Fire Alarm System 2 (Suite 121)

- **Means of Activation:**
  - Activation of Fire Alarm System 1
  - Pull stations at exit
  - Duct smoke detectors

- **Means of Notification:**
  - Voice Alarm speakers
  - Ceiling Strobes
  - FACP signals
  - DACT monitoring system
Performance Code Information

Codes Referenced:
2012 NFPA 101 Chapter 5

Models used:
Egress Analysis: Pathfinder- 2014 Edition
Performance Criteria

• Maintain tenable conditions for the duration of the Required Safe Egress Time → ASET ≥ RSET
  1. Visibility > 13 m (Assume unfamiliar occupants for a conservative analysis)
  2. Carbon Monoxide concentration < 1000 ppm
  3. Smoke layer Height > 1.83 m (6 ft)

• Prevent Flashover → Maintain upper layer temp < 500 °C
Design Fire Scenarios  (2012 NFPA 101 Section 5.5.3)

1. Occupancy Specific/activity related
2. Ultrafast-developing fire in primary means of egress
3. Normally unoccupied room
4. Concealed space next to large occupied room
5. Slowly developing fire, shielded from fire protection
6. Most Severe Fire/Largest Fuel Load
7. Outside Exposure Fire
8. Ordinary combustibles/Ineffective-unreliable fire protection
Fire Design Scenario 1: Basement Boiler Room Fire
Basement Fire Source

Slowly developing fire shielded from Fire Protection.
Basement Fire Source

High temperature sprinklers (rated at 286 °F) are some 20 feet above the fuel shown and very shielded by mechanical equipment and piping.
Basement Fire Source

Additional fuel in the SE corner of the boiler room to sustain a fire
Egress Component data applicable to every floor

<table>
<thead>
<tr>
<th>Egress Component</th>
<th>Width (inches)</th>
<th>Effective Width (inches) [feet]</th>
<th>Max. Specific flow (person/min/ft)</th>
<th>Max. Flow (person/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>East Stairway</td>
<td>60</td>
<td>48 [4.0]</td>
<td>18.5</td>
<td>74</td>
</tr>
<tr>
<td>West Stairway</td>
<td>60</td>
<td>48 [4.0]</td>
<td>18.5</td>
<td>74</td>
</tr>
<tr>
<td>East Stairway door</td>
<td>36</td>
<td>24 [2.0]</td>
<td>24</td>
<td>48</td>
</tr>
<tr>
<td>West Stairway door</td>
<td>36</td>
<td>24 [2.0]</td>
<td>24</td>
<td>48</td>
</tr>
</tbody>
</table>
Basement Egress calculations

Calculating RSET:

Pre-movement time = 30 Seconds

\[ S = k - akD = 212 - [(2.86)(212)(0.16)] = 97 \text{ ft/min} \]

Maximum Horizontal distance traveled =

\[ (140/2) + (50/2) = 125 \text{ ft.} \]

Time per floor = distance/speed = \( \frac{125 \text{ feet}}{97 \text{ feet/minute}} = 1.29 \) minutes.

Time through the stairway doors:

\[ t_p = \frac{P}{F_c} = \frac{\text{Population at pinch point}}{\text{Calculated flow}} \]

\[ = \frac{50}{\frac{2}{48 \text{ persons/minute}}} = 0.53 \text{ minutes} \]

Time needed to exit from basement area = 0.5 + 1.29 + 0.53 = 2.32 minutes = 140 seconds

Time comparison using Pathfinder was 111 seconds.
Basement Fire/Smoke Progression

- 40 Seconds
- 90 Seconds
- 140 Seconds
- 180 Seconds
Basement Visibility

140 Seconds
Basement Visibility

180 Seconds
Basement Heat Exposure

140 Seconds

Approximate Corridor Temp $\approx 45^\circ$C
Basement Heat Exposure

Approximate Corridor
Temp ≈ 65°C

Approximate Room
Temp ≈ 100°C

600 Seconds
Design Fire Scenario 2: 3rd Office Space

A space heater is left on for several hours in a workstation with an excessive combustible load causing a potential 1.5 MW fire.
Heat Release Rate 3rd Floor Fuel

Average HRR for computer components ≈ 1500 kW

Fig. C9. Workstation (2 panels), Sponsored by GSA and performed at BFRL in 1991

(c)2000 American Institute of Aeronautics & Astronautics or published with permission of author(s) and/or author(s)' sponsoring organization.
3\textsuperscript{rd} Floor Egress Calculations

Calculating RSET:

Pre-movement time = 30 Seconds
Occupant load = 146

Movement speed: \( S = k - akD = 212 - [(2.86)(212)(0.16)] = 97 \text{ ft/min} \)

Maximum Horizontal distance traveled = (140) + (50/2) = 165 ft.

Time per floor = distance/speed = \( \frac{165 \text{ feet.}}{97 \text{ feet/min}} = 1.7 \text{ minutes} \)

Time through the stairway doors:

\[
t_p = \frac{P}{F_c} = \frac{\text{Population at pinch point}}{\text{Calculated flow}} = \frac{146/2 \text{ persons}}{48 \text{ persons/minute}} = 1.52 \text{ minutes}
\]

Time needed to exit from 3\textsuperscript{rd} floor area = 0.5 + 1.7 + 1.52 = 3.72 minutes = 223 seconds

Comparative time using Pathfinder was 4.22 minutes (253 seconds)
Smoke Progression 3rd Floor

50 Seconds

150 Seconds

250 Seconds

420 Seconds
Visibility 3\textsuperscript{rd} Floor

50 Seconds
Visibility 3\textsuperscript{rd} Floor

250 Seconds
Carbon Monoxide Exposure 3rd Floor

50 Seconds
Carbon Monoxide Exposure 3rd Floor

250 Seconds
Heat Exposure 3rd Floor

250 Seconds
Sprinkler Activation Graph

Temperature °C

Time (s)

Sprinkler

SPRK

SPRK01

SPRK02

SPRK03
Untenable Conditions 3rd floor

CO Exposure
300 Seconds

Visibility
260 Seconds

Heat Exposure
800+ Seconds
Conclusions

• The building is compliant from a prescriptive standpoint.

The building’s size, height, type of construction, occupancy classifications, fire ratings, fire suppression, fire alarm systems, exiting arrangement, interior surfaces and architectural features meet all of the minimum code requirements for the code of record as well as the current codes. The occupants have adequate means of receiving notifications and have adequate means of egress in all parts of the building. The chances of survivability in a fire are very good and there is good redundancy of fire protection systems for life safety as well as property protection. There is a need however to install visual fire alarm notification devices (strobes).
Conclusions cont.

• The Basement fire scenario passes the performance test.

The fire size in the basement is not large enough to activate the sprinklers. The calculated required safe egress time is far shorter than the time when tenability conditions fall below target levels. Even during a fire in the basement which is mostly vacant, the smoke and other fire by-products only affect the corridor and exiting system if a door leading to the corridor is assumed to be left open. The high temperature sprinklers in the boiler room and other mechanical areas of the basement are somewhat shielded due to the amount of machinery in these areas. If there is a small fire in these areas, it is likely that the sprinklers will not activate, however since these areas are equipped with smoke detection the fire would be quickly discovered.
Conclusions cont.

• **The 3rd floor fire scenario passes the performance test.**
  The 3rd floor space heater fire is close to the maximum credible expected fire. The first sprinkler is activated in 70 seconds and the fire is kept under control. The occupants have adequate time to exit with the tenability conditions all in place. Even if one of the exits on the 3rd floor is unavailable, there is adequate time to reach the other exit in good visibility and low enough carbon monoxide levels. The smoke detection within the HVAC system would activate before the sprinklers and provide the means for notification, as well as the pull stations located at the exits.

Perhaps the most telling conclusion is that the prescriptive codes work. By following the prescriptive codes we provide adequate occupant and property protection for the building with the given likely fire scenarios of a particular occupancy.
Recommendations

• **Good Housekeeping**
  Both fire scenarios involved housekeeping issues. Section 304.1 of the 2013 CFC prohibits the accumulation of unnecessary combustible materials that may become fuel for a fire. This includes avoiding excessive accumulation of combustibles as well as keeping all paths of egress clear.

• **Preventative and corrective maintenance**
  Perform all scheduled preventative maintenance for boilers and other mechanical equipment to keep them working in a safe and proper working condition. All exit signs, egress lighting and emergency lighting must be kept in working order.
• **Keep Fire doors closed**
  Fire doors help prevent the passage of heat and smoke and they must be kept closed to function properly. In the basement fire scenario closed doors would have confined the fire to the boiler room and the occupants would not have been affected. Keeping stairway enclosure doors closed ensures that stairways serve as a safe haven from the fire hazards in the remainder of the building.

• **Fire Safety Education**
  Train staff/occupants on acceptable types of space heaters with built-in safety features. Have education campaigns on importance of keeping exit aisle ways clear. Also re-inforce requirements for immediate exiting when fire alarms are activated in order to reduce the pre-movement time. Train staff on importance of immediate exiting from spaces where Halon is about to be discharged, and other aspects of Halon system operations including the use of the discharge delay switch. Fire drills must to be held at least annually.