Culminating Project – 858N (The Fab)

By Daniel M. Garcia
Topics

- Overview
- Prescriptive Design
  - Structural Fire Protection
  - Fire Barriers & Egress
  - Fire Suppression Systems
  - Fire Alarm Systems
  - Smoke Management
  - Fire Management Program
- Performance-Based Design
  - Performance Approach and Criteria
  - Egress Analysis
  - Fire Scenarios
  - Other possible fire scenarios
- Recommendations
Applicable Codes & Standards

- DOE Standard 1066: Fire Protection Design Criteria
- Various Sandia Building and Fire Protection Specifications
OVERVIEW
The Fab Overview

- The Fab is a semiconductor facility (Primarily H-5)
- Also includes hazardous production material (HPM) storage, offices, and other support spaces
- Located on Kirtland Air Force Base (KAFB)
- The Fab is part of the 858 Complex (divided into 4 distinct facilities)
  - North (N), South (S), East Fab (EF), and East Lab (EL)
Fab Layout – Basement

~ 400 feet

~ 250 feet
PRESCRIPTIVE BASED DESIGN
Structural Analysis of the Fab

- **Building Construction Classification**
  - Technically considered as one-story with interstitial space and a basement (3 stories above grade plane allowed per IBC Table 504.4 for an H-5 Occupancy Type II-B sprinklered building)
  - Type II-N according to the UBC (1985 edition) – **Code of Record**
  - Type II-B according to the IBC (2015 edition)

- **Floors & Ceilings**
  - Double-tee pre-cast panel construction
  - Floors are not considered to be fire separated due to multiple penetrations. (Reason for occupancies of basement and interstitial.)

- **Roof**
  - Flat roof constructed of a steel deck with insulation and a membrane covering. (FM Type 1 Roofing System)
  - Roof height is approximately 28 feet. (75 feet allowed per IBC Table 504.3 for an H-5 Occupancy Type II-B sprinklered building)
CODE OF RECORD:
• Facility was originally designed as an “H-6” per the Uniform Building Code (1985).
• SSIFR Project (2015)
• Travel Distance Required: 75’
• Dead End Corridor Distance ≤ 20’
• Corridor width > 44”
Fire Barriers – 1st Floor of the Fab

- 2 HR barriers separating different occupancy types
- 4 HR barrier separating 858N and 858EF (both fabrication areas)
- 2 HR barrier between 858N and 858S (which is office space)
Egress Requirements (1st Floor)

IBC 415.10.3.3 (Service Corridors):
- Travel Distance $\leq 75\, ft$
- Dead ends $\leq 4\, ft$
- # of Exits $\geq 2$
- Not more than $\frac{1}{2}$ travel distance shall be through the fabrication area
- Doors shall swing in direction of egress
- Doors shall be self-closing
- The Fab service corridor (red box) meets these requirements

LSC 7.11 (High Hazard Contents):
- Two exits required unless:
  - Area of spaces $\leq 200\, ft^2$
  - Occupant Load $\leq 3$ people
  - Travel Distance $\leq 25\, ft$
- The Chemical Storage area and Room 1919 requires two exits (does not meet exemptions above)
- Travel distance $\leq 75\, ft$
- The Chemical Storage area (blue area) meets the requirements
- Room 1919 does not meet the requirements!
Both the basement and interstitial space have communicating areas to the first floor. Therefore despite some fire rated construction on the interstitial space, the floor has to be considered an H-5 occupancy.
Small door leads to a platform that leads to the roof.
# The Fab Occupant Load Factors

<table>
<thead>
<tr>
<th>Room</th>
<th>LSC (Ch. 6)</th>
<th>OLF ($ft^2$/person)</th>
<th>IBC (Ch. 3)</th>
<th>OLF ($ft^2$/person)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office</td>
<td>Business</td>
<td>100 gross</td>
<td>Business</td>
<td>100 gross</td>
</tr>
<tr>
<td>Laboratory</td>
<td>Business</td>
<td>100 gross</td>
<td>Business</td>
<td>100 gross</td>
</tr>
<tr>
<td>Mechanical Equipment Room</td>
<td>Industrial - General</td>
<td>100 gross</td>
<td>Accessory Storage Rooms</td>
<td>300 gross</td>
</tr>
<tr>
<td>General Storage</td>
<td>Storage other than Mercantile</td>
<td>500 gross</td>
<td>S-1 Storage</td>
<td>300 gross</td>
</tr>
<tr>
<td>Chemical Storage</td>
<td>Storage other than Mercantile</td>
<td>500 gross</td>
<td>H-5</td>
<td>200 gross</td>
</tr>
<tr>
<td>Cleanroom</td>
<td>Industrial - General</td>
<td>100 gross</td>
<td>H-5</td>
<td>200 gross</td>
</tr>
</tbody>
</table>

* IBC Commentary states if a specific type of occupancy is not found in the table to use the occupancy stated that it most closely resembles
Occupant Loads and Exit Capacities

Life Safety Code - Chapter 7

1st Floor (LSC)
Occupant Load: 594 people
Exits Required: 3 (actual 25)
Exit Capacity: 6,270 people

2nd Floor (LSC)
Occupant Load: 31 people
Exits Required: 2 (actual 2)
Exit Capacity: 147 people

Basement (LSC)
Occupant Load: 436 people
Exits Required: 2 (actual 2)
Exit Capacity: 587 people

International Building Code – Chapter 10

1st Floor (IBC)
Occupant Load: 377 people
Exits Required: 2 (actual 24)
Exit Capacity: 4,547 people

2nd Floor (IBC)
Occupant Load: 18 people
Exits Required: 2 (actual 2)
Exit Capacity: 147 people

Basement (IBC)
Occupant Load: 218 people
Exits Required: 2 (actual 2)
Exit Capacity: 587 people

- Two rooms have only exterior access: Each room has 1 occupant and one single-leaf exit door.
- Exits also meet exit layout requirements.
Smoke Control Analysis of the Fab

- Continuous operation of the fume exhaust/ no atriums (Dedicated Smoke Control System not required)
- Smoke detection in the return air system for the Fab.
- Smoke and heat vents required by IBC 415.6 when the area of a H-1, H-2, or H-3 occupancy is greater than 15,000 ft²
  - H-3 area in the the Fab is approximately 7,954 ft² (NOT REQUIRED)
- Per IBC 415.11.1.6 mechanical exhaust ventilation not less than $1 \frac{ft^3}{m}$ is required in fabrication area where HPMs are used or stored (PROVIDED IN THE FAB)
**Interior Finishes**

- The Fab is a production facility. Therefore, the amount of posters and displays on the walls is minimal. (Most of the 858 promotional material is in 858/South). Meets code.

<table>
<thead>
<tr>
<th>GROUP</th>
<th>SPRINKLERED</th>
<th>NONSPRINKLERED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Interior exit stairways, interior exit ramps and exit passageways</td>
<td>Corridors and enclosure for exit access stairways and exit access ramps</td>
</tr>
<tr>
<td>A-1 &amp; A-2</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>A-3&lt;sup&gt;f&lt;/sup&gt;, A-4, A-5</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>B, E, M, R-1</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>R-4</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>F</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>H</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>I-1</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>I-2</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>I-3</td>
<td>A</td>
<td>A&lt;sup&gt;i&lt;/sup&gt;</td>
</tr>
<tr>
<td>I-4</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>R-2</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>R-3</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>S</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>U</td>
<td>No restrictions</td>
<td>No restrictions</td>
</tr>
</tbody>
</table>

Table A 10.2.2 of the LSC (in the annex but assembled from the enforceable parts of the code in the main section) similarly gives requirements for interior finishes based on occupancy classification as shown in figure 2-11.
1st floor Sprinkler Systems
Basement Sprinkler System
2nd floor Sprinkler Systems
### Sprinkler System Design Criteria

<table>
<thead>
<tr>
<th>Space</th>
<th>Classification (NFPA 13)</th>
<th>Density (gpm/ft²)</th>
<th>Area (ft²)</th>
<th>Hose (gpm)</th>
<th>Design Demand (GPM @ PSI)</th>
<th>Duration (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean Rooms</td>
<td>Ordinary Hazard 2</td>
<td>0.14</td>
<td>3120</td>
<td>500</td>
<td>966.5 @58.9</td>
<td>30</td>
</tr>
<tr>
<td>Gowning Area</td>
<td>Ordinary Hazard 2</td>
<td>0.17</td>
<td>3000</td>
<td>500</td>
<td>1392 @36.4</td>
<td>60-90</td>
</tr>
<tr>
<td>Interstitial Space</td>
<td>Ordinary Hazard 2</td>
<td>0.20</td>
<td>3000</td>
<td>500</td>
<td>912.7 @43.87</td>
<td>-</td>
</tr>
<tr>
<td>Office Area</td>
<td>Ordinary Hazard 2</td>
<td>0.17</td>
<td>3000</td>
<td>500</td>
<td>1,191 @40.2</td>
<td>90-120</td>
</tr>
</tbody>
</table>

- Design for the duct sprinklers is 10 most remote sprinklers operating at minimum 30 psi each
- Class I standpipe system in the Fab
  - Supplied by the wet pipe risers through the cross mains.
  - Distributed in the corridors of all three floors.
Location of Flow Test Data (for Fab)

- Red circle indicates the Flow Test Hydrant
- 10” line to the North; 12” line to the West
- Water Flow Data (2005) is as follows:
  - 80 psi static and 74 psi residual @ a flow of 1,359 gpm
Sprinkler System Flow Data

Hydraulic Graph $N^{1.85}$ --- Pressure vs. Flow (Beta)

psi

85% Value

Static Point
Residual Point
Total Demand Point
Fab Special Suppression Systems

- Centralized $CO_2$ system serves the tools in the fab
  - Replaced multiple stand-alone and Halon 1301 systems that were tool specific. Cylinders in basement (below).
  - Discharge upon UV/IR detector activation (located at the tool level). Panel below.
Fire Alarm Systems in the Fab

- 858 Complex has a centralized fire alarm system (858/L)
  - Each facility's FACP reports to 858/L (reports to SNL)
  - Each facility has a NOTIFIER brand FACP
  - Each facility’s FACP also has MNS capabilities (e.g. mic)
- Analaser Ultra Sensitive Smoke Detection (USSD) System
  - Samples air circulating below floor tiles in the fab
Toxic Gas/ Fire Management Programs

- Gas monitoring system located inside the safety office
  - Reports safety incidents to 858/L
  - Has pull stations for multiple safety events (see below)
  - Fire Alarm Signal will shut down (hazardous) production gases

- Complex wide fire management program & training
  - Extensive exit signage and evacuation plans located throughout
PERFORMANCE BASED DESIGN
Performance Based Approach

- Assume occupants are familiar with the space, relatively healthy, and awake/alert
- Think about possible impacts to other facilities in the 858 Complex
Performance Based Criteria

- When people are to be protected from fire, performance criteria generally involve one or more of the following:
  1. Prevention of incapacitation by fire or smoke
  2. Prevention of thermal damage
  3. Providing sufficient visibility such that people can navigate means of egress.

Tenability Criteria (for Egress in a Corridor)

- Smoke Layer Height/Walking Surface: 6 feet (IBC 909.8.1)
- Visibility > 4 meters (SFPE Table 61.3 for familiar occupants)
- CO production < 1,400 ppm at 6 ft walking surface (Handbook of Smoke Control Engineering - HSCE)
- Temperature at walking surface < 66°C (HSCE, Figure 6.1)
Egress Analysis - Pathfinder

- Modeled first floor of the facility
  - Used the occupant load (most people were in Mech. Room)
- Had to close doors that are normally locked or controlled access (not meant for egress)
  - Example is the Chemical Storage Area
- Time to exit was approximately 79 seconds.
  - $+ \approx 10$ seconds for pre-movement $\approx 90$ second evacuation
Egress Analysis - Pathfinder
Exit time for Pathfinder Simulation

\[ RSET = t_d + t_{pm} + t_e = 30 \text{ seconds} + 10 \text{ seconds} + 80 \text{ seconds} = 120 \text{ seconds} \]

Where

- \( t_d \) = Time from fire ignition to detection
- \( t_{pm} \) = Pre-movement time
- \( t_e \) = Time from movement to when exit is reached

* Chosen \( t_d \) time is 30 seconds (Time for someone to pull the fire alarm)
Performance Based Scenario(s)

- NFPA 101 (LSC) gives 8 design fire scenarios
- LSC 5.2.2 states that each design fire shall be realistic with respect to at least one of the following scenario specifications
  - Initial fire location
  - Early rate of growth in fire severity
  - Smoke generation
- Based on concerns of occupants operations, I chose a fire close to design LSC fire scenario 2
  - Addresses concern of a reduction in the available means of egress
  - RSET = 120 seconds (means ASET > 120 seconds to pass)
Scenario - HF Acid/ Lab Coat Fire

- Chemicals are wheeled throughout the Fab from storage to where they are used (see route below)
- Path is directly through the main egress path of the Fab. Hydrofluoric Acid is main chemical of concern. Spill would hinder Emergency Response.
- Gowning items (coats and shoe covers) located in the egress path catch on fire from contractor hand tool.
- Scenario 1A assumes operational sprinklers in area.
Fire Scenario – Location in Corridor
Fire Location Near Occupants
Model for FDS – 1st Floor of the Fab
PyroSim Model – Tour Aisle Mesh
Lab coats or “Smocks” in the corridor are 98% polyester 2% carbon-fiber blend material (most combustible lab coat type!)

- Peak HRR of 1528 kW/m² and 720 s duration used (HRR drops down to 200 kW/m² and starts to decay)

Data Source: “CHARACTERIZING OF DESIGN FIRES FOR CLOTHING STORES” by Zalok & Hadjisphocleous
Heat Release Rate (1A & 1B)

Heat Release Rates for Fire Modeling Scenarios

**Scenario 1B - NO Sprinklers**

**Scenario 1A - With Sprinklers**
Sprinkler Activation Times – 1A

DEVICE Activation Times

1  SPRK02  237.8 s
2  SPRK01  263.7 s
3  SPRK06  189.2 s
4  SPRK03  224.3 s
5  SPRK04  208.4 s
6  SPRK05  187.6 s
Fire Modeling Tenability Results 1A

NOTE: Sprinklers have been omitted from Smoke View screenshots for clarity
Max Temperature@ 294 seconds ≈ 170°C >> 66°C at 6 ft walking surface
> 66°C at ~ 2 minutes 🔄 Does not meet tenability criterion!
Fire Modeling Tenability Results 1A

Max CO production = 1,500 ppm @ 523 seconds > 1,400 ppm at 6 ft walking surface

> 1,400 ppm at ~ 3.5 minutes  🟢 Meets tenability criterion!
Fire Modeling Tenability Results 1A

Visibility ≈ 0 meters @ 125 seconds at 6 ft walking surface
< 4 meters at ~ 100 seconds  ◇ Does not meet tenability criterion!
Corridor View (Top View) 1A

At 0 seconds into simulation

At 30 seconds into simulation

At 69 seconds into simulation

At 257 seconds into simulation
Corridor View 1A (Viewpoint inside)

At 0 seconds into simulation

At 50 seconds into simulation

At 60 seconds into simulation

At 105 seconds into simulation
Scenario 1B – No sprinklers during fire

• There is a possibility that the sprinkler system might be shut down for construction and a lab coat fire occurs. (NOTE: SNL has a policy against hot work occurring while a sprinkler system is impaired.)
Fire Modeling Tenability Results 1B

NOTE: Sprinklers have been omitted from Smoke View screenshots for clarity.

Temperature@ 360 seconds \(\approx 270^\circ C \geq 66^\circ C\) at walking surface

\(\geq 66^\circ C\) at approximately 130 seconds 🟢 Meets tenability criterion!
Fire Modeling Tenability Results 1B

CO production = 10,000 ppm@ 501 seconds  >> 1,400 ppm at 6 ft walking surface

> 1,400 ppm at ~ 187 seconds  Meets tenability criterion!
Fire Modeling Tenability Results 1B

Visibility $\approx 0$ meters @ 114 seconds at 6 ft walking surface

$< 4$ meters at $\sim 115$ seconds  

Does not meet tenability criterion!
Corridor View (Viewpoint inside) 1B

At 0 seconds into simulation

At 50 seconds into simulation

At 30 seconds into simulation

At 120 seconds into simulation
Smoke Layer Height Descent (1A/1B)

Smoke Layer Height Descent for Fire Modeling Scenarios

- Scenario 1B - No Sprinklers
- Scenario 1A - With Sprinklers
## Comparison of both fire scenarios

<table>
<thead>
<tr>
<th>Tenability Criteria (at 6 ft walking level)</th>
<th>Scenario 1A Time to Failure (With Sprinklers)</th>
<th>Scenario 1B Time to Failure (Without Sprinklers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (under 66°C)</td>
<td>2 minutes</td>
<td>2 minutes, 10 seconds</td>
</tr>
<tr>
<td>CO Production (under 1,400 ppm)</td>
<td>3.5 minutes</td>
<td>3 minutes, 7 seconds</td>
</tr>
<tr>
<td>Visibility (greater than 4 meters)</td>
<td>1 minute, 20 seconds</td>
<td>1 minute, 55 seconds</td>
</tr>
</tbody>
</table>

- Conclusion – Visibility fails whether or not sprinklers are present but sprinklers overall reduce the maximum temperature and CO produced. Overall: RSET < ASET (Also known that fire will block an exit.)
Other possible fire scenarios

- Chemical waste fire in the basement (see pictures below of the waste solvent collection system).
- Chemical (e.g. acetone) fire in a clean room bay ignites the lab coat of a worker or possible tool fire.
- Contractor ignites combustibles from hot work in the basement. (Hot work is normally permitted.)
<table>
<thead>
<tr>
<th>Recommendation</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Add an exit to the exterior in RM 1919.</td>
<td>RM 1919 falls under the high hazard provisions of NFPA 101. With no exterior exit and only one interior exit, it currently doesn’t meet the NFPA 101 requirements (see slide 11).</td>
</tr>
<tr>
<td>2 Perform new flow test.</td>
<td>The flow test used for analysis (see slide 17) is out of date by quite a few years. NFPA requires recent flow test data to be used. At the time of this presentation, a new flow test was not able to be performed.</td>
</tr>
<tr>
<td>3 Reconstitute hydraulic calculations</td>
<td>Original hydraulic design calculations are not available. Have a NICET IV level sprinkler designer (contractor) perform calculations using sprinkler drawings and SNL approved hydraulic calculation software. Consider using extra hazard occupancy for chemical storage area design to check water supply adequacy (see slide 19).</td>
</tr>
<tr>
<td>4 Move gowning operations from the corridors to a dedicated space</td>
<td>Lab coats can catch fire and should not be located in an egress corridor. Plans are underway for a dedicated gowning storage space. (See slide 36)</td>
</tr>
<tr>
<td>5 Don’t move acid through an egress corridor.</td>
<td>An acid spill would cause a major hazard in an egress area and impede emergency response. (See slide 36)</td>
</tr>
</tbody>
</table>
THANK YOU! ANY QUESTIONS?

Special Thanks to my Professors, SNL colleagues, and my family!!
Fab Sprinkler Systems

- All sprinkler piping is seismically protected IAW NFPA 13
- Sprinkler Heads: 5.6K @ 155°F & 165°F
- Water supply provided by nearby water mains
  - Risers #1 and #3 fed from the West water main
  - Riser #2 fed from the North water main
  - KAFB water lines are connected to the city of Albuquerque
  - Pressure is boosted by 3 large KAFB owned tanks
- Riser #1 (Wet pipe system)
  - 2 1/2” and 4” mains and 2” and 1 1/2” branch lines
- Riser #2 (Wet pipe system)
  - 3” and 4” mains and 1 1/2” branch lines
- Riser #3 (Wet pipe fire cycle system)
  - Valved from Riser #1 (does not have its own service entrance)
  - 8 sprinklers protect two rooms (turn on/off from heat detectors)