Fire Protection Engineering
FPE S596 Culminating project
Jacob Epstein
Final Presentation

June 15, 2017
ACME Semiconductor Fab

- Building Description
- Applicable Codes & Standards
- Prescriptive Requirements
  - Structural Fire Protection
  - Fire Sprinkler
  - Fire Alarm
  - Means of Egress
- Performance Based Design
ACME Semiconductor Fab Expansion

- Semiconductor Fabrication Support / 231,000 square feet
- Cleanroom / 145,000 square feet
- Hazardous Production Material (HPM) Storage or Dispensing / 28,000 square feet
- Exterior Loading Docks / 3,600 square feet
- Pyrophoric Storage / 430 square feet
Applicable Codes & Standards

- 2012 International Fire Code (IFC).
- Factory Mutual (FM) Datasheet 7-29, “Flammable Liquid Storage in Portable Containers.”
- FM Datasheet 7-50, “Compressed Gases in Cylinders.”
- FM Datasheet 7-84, “Hydrogen Peroxide.”
- FM Datasheet 7-88, “Storage Tanks for Flammable Liquids.”
- Society of Fire Protection Engineers (SFPE) Handbook of Fire Protection Engineering, 4th Edition
# Occupancy Classification

<table>
<thead>
<tr>
<th>Description of Use</th>
<th>Occupancy Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fabrication Areas</td>
<td>Semiconductor (Group H-5)</td>
</tr>
<tr>
<td>Flammable Liquid Storage</td>
<td>High Hazard (Group H-2)</td>
</tr>
<tr>
<td>Hazardous Material Storage</td>
<td>High Hazard (Group H-3)</td>
</tr>
<tr>
<td>Corrosive/Oxidizer Storage</td>
<td>High Hazard (Group H-4)</td>
</tr>
<tr>
<td>Mechanical &amp; Electrical Rooms</td>
<td>Factory (Group F-1)</td>
</tr>
</tbody>
</table>
# Structural Fire Protection

## Building Elements - Based on Type I-B Construction

<table>
<thead>
<tr>
<th>Building Element</th>
<th>IBC Required Fire Resistance Rating</th>
<th>Provided Fire Resistance Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural Frame</td>
<td>2 Hour</td>
<td>2 Hour</td>
</tr>
<tr>
<td>Bearing Walls (exterior)</td>
<td>2 Hour</td>
<td>2 Hour</td>
</tr>
<tr>
<td>Bearing Walls (interior)</td>
<td>2 Hour</td>
<td>2 Hour</td>
</tr>
<tr>
<td>Nonbearing Walls (exterior) (&lt;30 feet)</td>
<td>1 Hour</td>
<td>1 Hour</td>
</tr>
<tr>
<td>Unprotected Openings (IBC Section 705.8)</td>
<td>Protection Required (footnote i), if less than 30 feet fire separation</td>
<td>None, fire separation distances &gt; 30 feet</td>
</tr>
<tr>
<td>Nonbearing Walls (interior)</td>
<td>0 Hour</td>
<td>0 Hour</td>
</tr>
<tr>
<td>Floor Construction</td>
<td>2 Hour</td>
<td>2 Hour</td>
</tr>
<tr>
<td>Roof Construction*</td>
<td>1 Hour</td>
<td>1 Hour*</td>
</tr>
<tr>
<td>Shaft Enclosures (IBC Section 713.4)</td>
<td>2-hour</td>
<td>2 Hour</td>
</tr>
<tr>
<td>Stairwell Enclosures (IBC Section 713.4)</td>
<td>2-hour</td>
<td>2 Hour</td>
</tr>
<tr>
<td>Exit Passageways - to extend travel distance</td>
<td>2 Hour</td>
<td>2 Hour</td>
</tr>
</tbody>
</table>

*Roof construction meeting the 1 hour fire resistance rating requirement will be shown through an alternative method complying with Section 104.11. The use of fire modeling will show a fire resistance rating without the use of spray-applied fire resistive materials, when exposed to the worst case credible fire scenario.*
Fire Protection Systems

- Water Supply

24” CITY WATER MAIN
Fire Protection Systems

- Electric fire pump & diesel fire pump
- 266,000 gallon on-site emergency water storage tank.
## HPM Rooms & Design Densities

<table>
<thead>
<tr>
<th>Room / Area (Room Number)</th>
<th>Density (gpm/sq. ft.)</th>
<th>Area of Operation (sq. ft.)</th>
<th>NFPA Reference</th>
<th>FM Datasheet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk Aqueous Chemical Room (F11121)</td>
<td>0.20</td>
<td>3,000</td>
<td>NFPA 430, Section 5.3.2 (3)</td>
<td>7-84</td>
</tr>
<tr>
<td>Specialty Gas Dispensing (F111122)</td>
<td>0.25</td>
<td>3,000</td>
<td>NFPA 55, Section 6.9.2.2</td>
<td>7-50</td>
</tr>
<tr>
<td>Bulk Gas Purifier Room (F11821)</td>
<td>0.30</td>
<td>2,500</td>
<td>NFPA 13, Figure 11.2.3.1.1 / AM&amp;M #12</td>
<td>-</td>
</tr>
<tr>
<td>Aqueous Chemical Room (F111021)</td>
<td>0.20</td>
<td>Entire Room (~2,400)</td>
<td>NFPA 430, Table 6.4.1</td>
<td>-</td>
</tr>
<tr>
<td>Solvent Room (F141211)</td>
<td>0.30</td>
<td>Entire Room (~3,250)</td>
<td>-</td>
<td>FM DS 7-88, Table 11.</td>
</tr>
<tr>
<td>Solvent Offloading (Deluge System)</td>
<td>0.30</td>
<td>Entire Area (&lt;3,900)</td>
<td>NFPA 15, Section 7.3.3.2</td>
<td>FM DS 4-1N</td>
</tr>
<tr>
<td>Cold Storage (F141214)</td>
<td>0.60</td>
<td>Entire Room (~693)</td>
<td>-</td>
<td>FM DS 7-29, Table 15</td>
</tr>
<tr>
<td>Bottle Staging (F111212/F111213)</td>
<td>0.60</td>
<td>Entire Room (~442)</td>
<td>-</td>
<td>FM DS 7-29, Table 15</td>
</tr>
<tr>
<td>Acid/Base Small Pack (F111205)</td>
<td>0.60</td>
<td>Entire Room (~220)</td>
<td>-</td>
<td>FM DS 7-29, Table 15</td>
</tr>
<tr>
<td>Solvent Waste Room (F111402)</td>
<td>0.30</td>
<td>Entire Room (&lt;3,000)</td>
<td>NFPA 30, Table 16.5.2.2</td>
<td>-</td>
</tr>
<tr>
<td>Waste Pit &amp; IWD Treatment (F11011)</td>
<td>0.20</td>
<td>3,000</td>
<td>NFPA 13, Figure 11.2.3.1.1</td>
<td>-</td>
</tr>
<tr>
<td>Hazardous Material Delivery Area (F111301)</td>
<td>0.20</td>
<td>Entire Area (&lt;3,900)</td>
<td>NFPA 13, Figure 11.2.3.1.1 and Section 11.2.3.2.5</td>
<td>-</td>
</tr>
<tr>
<td>NE Offload Dock (outside F111402)</td>
<td>0.20</td>
<td>Entire Area (&lt;3,900)</td>
<td>NFPA 13, Figure 11.2.3.1.1 and Section 11.2.3.2.5</td>
<td>-</td>
</tr>
</tbody>
</table>
Fire Protection Systems

- Supply / demand curve
- Special suppression systems
  - CO2 local application at flammable gas valve manifold boxes (VMBs) initiated by UV/IR flame detectors
Fire Protection Systems

WATER SUPPLY ANALYSIS
Static: 61.20 psi Resid: 60.30 psi Flow: 1500.0 gpm

Flow 1
Static PSI
Residual PSI
Pitot PSI
Orifice Diameter
Coefficient of Discharge
GPM
Date
Location
By Who

A. Source Supply Curve
B. Net Pump Discharge Curve
C. Pump Discharge Curve
D. System Demand Curve
E. Available at Source
F. Available at Pump Suction
Fire Alarm Systems

- Manual fire alarm system (IBC 415.10.8)
- Automatic smoke detection for highly toxic gases, organic peroxides, and oxidizers (907.2.5)
- Emergency alarm system (908.2)
  - Continuous gas detection of highly toxic or toxic gas at or below the permissible exposure limit (PEL)
  - Initiates a local alarm and transmit to supervising station
Fire Alarm Systems
Means of Egress

Door 79 occ
31.6"
34"

H3/H4
WASTE CHEMS
2,532 SF
200
13 OCC

H3/H4
SOLVENT ROOMS
4,236 SF
200
23 OCC

H3/H4
CHEM ROOMS
1,550 SF
200
8 OCC

Door 84 occ
33.6"
34"

NORTH
## Means of Egress

<table>
<thead>
<tr>
<th>Floor Level (Floor Name) (Elevation above grade)</th>
<th>No. of Occupants</th>
<th>No. of Exits Required</th>
<th>No. of Exits Provided</th>
<th>Exit Width Required</th>
<th>Exit Width Provided**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1 (Subfab) (0’-0&quot;)</td>
<td>659</td>
<td>3</td>
<td>14</td>
<td>263.6”</td>
<td>476”</td>
</tr>
<tr>
<td>Level 1-M (Equip. Platform) (13’-0&quot;)</td>
<td>312</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 2 (Mechanical Mezzanines) (17’-4&quot;)</td>
<td>117</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 1-M &amp; Level 2 converge</td>
<td>429</td>
<td>2</td>
<td>4</td>
<td>171.6”</td>
<td>136”</td>
</tr>
<tr>
<td>Level 3 (Cleanroom) (32’-4&quot;)</td>
<td>703</td>
<td>3</td>
<td>8</td>
<td>281.2”</td>
<td>352”</td>
</tr>
<tr>
<td>Level 4 (Interstitial catwalks) (60’-2&quot;)</td>
<td>152</td>
<td>2</td>
<td>4</td>
<td>60.8”</td>
<td>136”</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1,918</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Smoke Management

- Highest occupied floor level elevation – 72’-6”
  - Not a high-rise, smokeproof enclosures not required
- Smoke management is through passive fire barriers between adjacent smoke zones (fire-rated floor/ceiling assemblies, fire-rated vertical exit enclosures)
Fire Management

- Emergency Response Team (ERT)
- Local volunteer fire department
- Hot-work programs
- Fire extinguisher training
Performance Based Design

Design Objective:
Provide roof construction achieving a 1-hour fire resistance rating when subjected to the worst credible fire scenario. Fire modeling will be used to show a 1-hour fire resistance rating without the use of spray-applied fire resistive materials.

Stakeholders:
Design Team, General Contractor, Owner, AHJ
Structural Fire Exposure

- Room Geometry
- Fuel Load
- Fire Characteristics

FIRE MODEL

Fire thermal exposure
Design Fire Scenario
Design Fire Scenarios

- **Wet Bench**
  - Materials of construction – various plastics
  - Weighted average $m'' = 0.0040 \text{ kg/m}^2\text{s}$, $\Delta H_c = 7.94 \text{ MJ/kg}$
  - Isopropyl alcohol (IPA) & Tetramethylammonium hydroxide (TMAH)
  - maximum HRR would be 524 kW

- **Front Opening Unified Pod (FOUP)**
  - Materials of construction – polycarbonate
  - $m'' = 0.025 \text{ kg/m}^2\text{s}$, $\Delta H_c = 21.2 \text{ MJ/kg}$
  - maximum HRR is 79.5 kW

\[ HRR = Q_c = m'' \times \Delta H_c \]

- No local suppression within Wet Bench tools
Ventilation limited compartment fire
The maximum HRR is dependent on the quantity of oxygen available for combustion of the materials within the compartment.

Adequate vents are not readily observed on the SU-3100
Assumed that two of the upper doors on both sides of the equipment are open or have been removed to provide a worst-case ventilation condition.

Using the Babrauskas Method, the maximum HRR for a ventilation-limited fire within a compartment is:

\[ HRR = 1500 A_o \sqrt{H_o} \]

where:
- \( A_o \) = area of vent opening (m²)
- \( H_o \) = height of bottom of vent opening (m)

Each of the four assumed openings has an area of approximately 0.27 m² and a height of 2.4 m. Therefore, the maximum HRR for this compartment, regardless of internal fuels, is 2,509.7 kW.
Design Fire Scenario

<table>
<thead>
<tr>
<th>Fuel Source</th>
<th>Peak HRR</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet Bench (center)</td>
<td>2510 kW</td>
<td>(divided equally among (4) vents)</td>
</tr>
<tr>
<td>FOUPs (on center bench)</td>
<td>237 kW</td>
<td>(divided equally among (3) FOUPs)</td>
</tr>
<tr>
<td>Wet Bench #2 (left)</td>
<td>1205 kW</td>
<td>(divided equally among (2) vents)</td>
</tr>
<tr>
<td>Wet Bench #3 (right)</td>
<td>1205 kW</td>
<td>(divided equally among (2) vents)</td>
</tr>
<tr>
<td>Adjacent FOUPs (on adjacent wet benches)</td>
<td>158 kW</td>
<td>(divided equally among (2) FOUPs)</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>5,415 kW</strong></td>
<td></td>
</tr>
</tbody>
</table>
Evaluate Trial Design (FDS)

Time evolution of grid ceiling and steel truss gas temperatures
Evaluate Trial Design

Temperature slice file showing heat transfer through ceiling
Evaluate Trial Design

Ceiling Tile Failure - Ceiling & Beam Temperatures

Time evolution of grid ceiling and steel truss gas temperatures with ceiling failure
Evaluate Trial Design

Temperature slice file showing peak interstitial temperatures with ceiling tile failure
Evaluate Trial Design

Temperature slice file showing interstitial temperatures with multiple tile failures
Structural Fire Exposure

- Element Geometry
- Thermal Properties
- Heat Transfer Coefficients

HEAT TRANSFER MODEL

Thermal gradients
LHCA – W14x283 under STTC

\[
\begin{align*}
\varepsilon &= 0.7 \\
c_s &= 600.00 \text{ J/Kg·K} \\
\sigma &= 5.67E-08 \text{ W/(m}^2\cdot\text{K}^4) \\
\rho &= 7.86E+03 \text{ Kg/m}^3 \\
W/D &= 2.968 \text{ lbs/ft·in} = 173.8925 \text{ Kg/m}^2 \\
\Delta t &= 10.00 \text{ Seconds}
\end{align*}
\]

<table>
<thead>
<tr>
<th>Seconds</th>
<th>Time</th>
<th>T_s (°C)</th>
<th>T_f (°C)</th>
<th>T_f-T_s (°C)</th>
<th>h_t</th>
<th>\Delta T_s (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>20.00</td>
<td>20.00</td>
<td>0.0025</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>20.00</td>
<td>164.96</td>
<td>144.9633.0703</td>
<td>0.459464</td>
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<tr>
<td>20</td>
<td>20</td>
<td>20.46</td>
<td>217.51</td>
<td>197.0535.1838</td>
<td>0.664478</td>
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<tr>
<td>30</td>
<td>30</td>
<td>21.12</td>
<td>255.18</td>
<td>234.0536.9485</td>
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<tr>
<td>40</td>
<td>40</td>
<td>21.95</td>
<td>285.26</td>
<td>263.3138.5225</td>
<td>0.972195</td>
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<tr>
<td>1 Min.</td>
<td>50</td>
<td>22.92</td>
<td>310.57</td>
<td>287.6539.9689</td>
<td>1.101923</td>
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<tr>
<td>240</td>
<td>240</td>
<td>59.85</td>
<td>532.52</td>
<td>472.6759.369</td>
<td>2.689592</td>
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<tr>
<td>400</td>
<td>400</td>
<td>109.37</td>
<td>615.16</td>
<td>505.7972.213</td>
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</tr>
<tr>
<td>560</td>
<td>560</td>
<td>169.82</td>
<td>669.36</td>
<td>499.5384.678</td>
<td>4.054171</td>
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<tr>
<td>720</td>
<td>720</td>
<td>237.60</td>
<td>708.84</td>
<td>471.2497.6355</td>
<td>4.409812</td>
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<tr>
<td>900</td>
<td>900</td>
<td>318.93</td>
<td>742.78</td>
<td>423.85113.303</td>
<td>4.60273</td>
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</tr>
<tr>
<td>1200</td>
<td>1200</td>
<td>456.48</td>
<td>784.56</td>
<td>328.09142.206</td>
<td>4.471702</td>
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<tr>
<td>1500</td>
<td>1500</td>
<td>582.72</td>
<td>815.28</td>
<td>232.56173.045</td>
<td>3.857146</td>
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<tr>
<td>2400</td>
<td>2400</td>
<td>815.07</td>
<td>875.32</td>
<td>60.25247.366</td>
<td>1.42844</td>
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<tr>
<td>1 Hour</td>
<td>3600</td>
<td>908.21</td>
<td>923.56</td>
<td>15.35292.07</td>
<td>0.429712</td>
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</tr>
</tbody>
</table>

Valid for F/V = 37.45 m⁻¹
The exposed steel structure does not reach a temperature of $XXX^\circ F$ ($XXX^\circ C$) for simulation duration of one hour.

This temperature is the point at which a truss deflection of $xx$ mm occurs, which is deemed a failure point by the design team.

ASTM E119 test criteria used for the establishment of fire-resistance ratings, exceeding a temperature of $1,100^\circ F$ (593°C) average over 4 thermocouples at any section, is deemed failing a loaded restrained beam.
Design Loads

- Fire Load = 1.2D + 0.5L + 0.2W

**FAB Area**

- **i) Roof Level:**
  - Superimposed Dead Load (DL):
    - Rigid Insulation (8-in)
      - 12 psf
    - Single-ply Roof Membrane
      - 1 psf
    - 3" Deep Steel Deck
      - 3 psf
    - Miscellaneous
      - 4 psf
    - **Total DL = 20 psf**
  
  - Hanging Dead Load (HDL):
    - MEP Below Truss Top Chord
      - 10 psf
    - MEP & Sprinklers Below Truss Bottom Chord
      - 20 psf
    - Catwalk DL
      - 2 psf
    - Ceiling
      - 15 psf
    - AMHS System
      - 8 psf
    - **Total HDL = 55 psf**

  - Superimposed Live Load (LL):
    - Roof Live Load (Snow)
      - 25 psf (Non-reducible)
    - Truss Bottom Chord Live Load
      - 10 psf (Non-reducible)
    - Catwalk LL
      - 5 psf
    - **Total LL = 40 psf**
Performance Criteria

- Maximum deflection of xx mm.
Recommendations

- Perform finite element heat transfer analysis.
- Use results of heat transfer analysis as input to structural model.
- Conduct structural calculations in reverse using assumed maximum permitted deflection criteria to determine critical design temperature.
Questions?

Contact
Jacob Epstein, P.E.
+1 602-286-6000
jepstein@jensenhughes.com