UW Burke Museum
Seattle, WA
Justin Schmidt
Outline

• Review of Building Components
  • Construction Type
  • Occupancy
  • Egress Requirements
  • Fire Alarm
  • Fire Suppression

• Atrium Design Analysis
  • Prescriptive Code
    • Section 404 Compliant
  • Alternate Design
    • Creating Separations
Codes and Standards

- 2012 IBC
- NFPA 92
- NFPA 72
- NFPA 13
Building Summary

- New 105,000 GSF Museum
  - Galleries
  - Labs
  - Storage Rooms
  - Offices
  - Work Rooms
  - Classrooms
  - Café
- Three Stories Over a Partial Basement
- Fully Sprinkled
## Construction Type II-B

<table>
<thead>
<tr>
<th>BUILDING ELEMENT</th>
<th>TYPE I</th>
<th>TYPE II</th>
<th>TYPE III</th>
<th>TYPE IV</th>
<th>TYPE V</th>
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<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>A^d</td>
<td>B</td>
<td>HT</td>
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<tr>
<td>Primary structural frame (see Section 202)</td>
<td>3^a</td>
<td>2^a</td>
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<tr>
<td>Bearing walls</td>
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<td>Exterior^f,g</td>
<td>3</td>
<td>2</td>
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<tr>
<td>Interior</td>
<td>3^a</td>
<td>2^a</td>
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<td>Nonbearing walls and partitions</td>
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<td>See Table 602</td>
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<tr>
<td>Exterior</td>
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<tr>
<td>Nonbearing walls and partitions Interior^e</td>
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<td>0</td>
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<td>Floor construction and associated secondary member (see Section 202)</td>
<td>2</td>
<td>2</td>
<td>1</td>
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<td>Roof construction and associated secondary members (see Section 202)</td>
<td>1^(1/2)b</td>
<td>1^b.c</td>
<td>1^b,c</td>
<td>0c</td>
<td>1^b.c</td>
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</tbody>
</table>
Building Height and Area

- Proposed
  - Building Height: 64’
  - Area Per Story: 28,771 SF
BUILDING AREA MODIFICATIONS, PER 506

FRONTAGE INCREASE FACTOR (If) PER 506.2, EQUATION 5-2:
BUILDING PERIMETER THAT FRONTS ONTO A PUBLIC WAY = 860'
PERIMETER OF ENTIRE BUILDING = 860'
WIDTH OF PUBLIC WAY = 30'
If = (860'/860' – 0.25) 30'/30'
If = 0.75

SPRINKLER INCREASE FACTOR (Is) PER 506.3 = 2

SPRINKLER AND FRONTAGE INCREASE PER 506.1, EQUATION 5.1:
Aa = ALLOWABLE BUILDING AREA/ STORY
TABULAR BUILDING AREA PER STORY IN ACCORDANCE WITH TABLE 503 = 9,500

Aa = {9500 + [9500 X 0.75] + [9500 X 2]} = 16,625 + 19,000 = 35,625 SF
Building Height and Area

- Proposed
  - Building Height: 64’
  - Area Per Story: 28,771 SF

- Allowed: Type II-B with Sprinklers and Frontage Increase
  - Building Height: 75’
  - Area Per Story: 35,625 GSF
Occupancy

• Non-Separated
  • A-3: Assembly, Museums, Lecture Halls (Primary Occupancy)
  • A-2: Assembly, Food and Drink Consumption
  • B: Business, Administration Areas
  • E: Educational Areas
  • S-1: Storage, Moderate-Hazard
  • S-2: Storage, Low-Hazard
  • M: Mercantile

• Separated Accessory
  • H-3: Hazardous, containing class IB Flammable or Comestible Liquids
Occupancy, Basement Level

Exit Access

Exit

A-3
A-2
B
E
S1
S2
H3
M

CAL POLY
Fire Protection Engineering
Occupancy, Level 2
Occupancy, Level 3
# OCCUPANT LOAD CALCULATIONS

<table>
<thead>
<tr>
<th>Name</th>
<th>Function</th>
<th>OCCUPANCY</th>
<th>AREA</th>
<th>OCCUPANT LOAD FACTOR</th>
<th>NET/GROSS</th>
<th>OCCUPANTS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SECOND LEVEL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OFFICES, WORK AREAS</td>
<td>BUSINESS AREAS (WITH SPRINKLERS)</td>
<td>B</td>
<td>933 SF</td>
<td>130 SF</td>
<td>GROSS</td>
<td>7</td>
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<tr>
<td>EXHIBIT GALLERY</td>
<td>ASSEMBLY EXHIBIT</td>
<td>A-3</td>
<td>2,576 SF</td>
<td>30 SF</td>
<td>NET</td>
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<tr>
<td>EXHIBIT GALLERY</td>
<td>ASSEMBLY EXHIBIT</td>
<td>A-3</td>
<td>2,433 SF</td>
<td>30 SF</td>
<td>NET</td>
<td>81</td>
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<td>EXPERIENCE ACOVE</td>
<td>ASSEMBLY EXHIBIT</td>
<td>A-3</td>
<td>663 SF</td>
<td>30 SF</td>
<td>NET</td>
<td>22</td>
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<tr>
<td>OFFICES, LIBRARY</td>
<td>BUSINESS AREAS (WITH SPRINKLERS)</td>
<td>B</td>
<td>4,202 SF</td>
<td>130 SF</td>
<td>GROSS</td>
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<tr>
<td>LAB</td>
<td>COMMERCIAL LABORATORIES</td>
<td>B</td>
<td>768 SF</td>
<td>100 SF</td>
<td>GROSS</td>
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<td>STORAGE</td>
<td>ACCESSORY STORAGE AREAS, MECHANICAL EQUIPMENT ROOMS</td>
<td>S-1</td>
<td>368 SF</td>
<td>300 SF</td>
<td>GROSS</td>
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<td>LAB</td>
<td>COMMERCIAL LABORATORIES</td>
<td>B</td>
<td>275 SF</td>
<td>100 SF</td>
<td>GROSS</td>
<td>3</td>
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<tr>
<td>LABS</td>
<td>COMMERCIAL LABORATORIES</td>
<td>B</td>
<td>2,506 SF</td>
<td>100 SF</td>
<td>GROSS</td>
<td>25</td>
</tr>
<tr>
<td>EXHIBIT PATHWAY</td>
<td>AIRPORT TERMINAL CONCOURSE</td>
<td>A-3</td>
<td>1,070 SF</td>
<td>100 SF</td>
<td>GROSS</td>
<td>10</td>
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<td>STORAGE</td>
<td>ACCESSORY STORAGE AREAS, MECHANICAL EQUIPMENT ROOMS</td>
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<td>5,688 SF</td>
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<td>18</td>
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<td>STORAGE</td>
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<td>300 SF</td>
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<tr>
<td>ROOM</td>
<td>BUSINESS AREAS (WITH SPRINKLERS)</td>
<td>B</td>
<td>60 SF</td>
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<td>STORAGE</td>
<td>ACCESSORY STORAGE AREAS, MECHANICAL EQUIPMENT ROOMS</td>
<td>S-1</td>
<td>442 SF</td>
<td>300 SF</td>
<td>GROSS</td>
<td>1</td>
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<tr>
<td>STORAGE</td>
<td>ACCESSORY STORAGE AREAS, MECHANICAL EQUIPMENT ROOMS</td>
<td>H-3</td>
<td>701 SF</td>
<td>300 SF</td>
<td>GROSS</td>
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<tr>
<td><strong>SECOND LEVEL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>298</td>
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</tbody>
</table>

# OCCUPANT LOAD CALCULATIONS

<table>
<thead>
<tr>
<th>Name</th>
<th>Function</th>
<th>OCCUPANCY</th>
<th>AREA</th>
<th>OCCUPANT LOAD FACTOR</th>
<th>NET/GROSS</th>
<th>OCCUPANTS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SECOND LEVEL - MEZZANINE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OFFICES, WORK AREAS</td>
<td>BUSINESS AREAS (WITH SPRINKLERS)</td>
<td>B</td>
<td>2,792 SF</td>
<td>130 SF</td>
<td>GROSS</td>
<td>21</td>
</tr>
<tr>
<td><strong>SECOND LEVEL - MEZZANINE</strong></td>
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<td></td>
<td></td>
<td>21</td>
</tr>
</tbody>
</table>
Fire Suppression (Second Floor)

Ordinary Hazard Group 1: 0.15 GPM at 1,500 SF
Ordinary Hazard Group 2: 0.2 GPM at 1,500 SF
Extra Hazard, Group 2: 0.6 GPM at 2,500 SF (625 SF Actual)
Atrium Design Analysis

• Prescriptive Code
  • Section 404 Compliant

• Alternate Means and Methods
  • Horizontal Separations

• Bases of Analysis
  • Code Compliance
  • Performance per FDS Model
  • Affect on Architectural Design
Atrium Layout

Openings Above

Open to Below

Level 1
Atrium Layout

Four Story Atrium
Prescriptive Atrium Design (section 404 IBC)

• The atrium floor area is permitted to be used for any approved use where the individual space is provided with an automatic sprinkler system in accordance with Section 903.3.1.1.

• An automatic sprinkler system shall be installed through the entire building
  • Exceptions 2: Where the ceiling of the atrium is more than 55 feet above the floor, sprinkler protection at the ceiling of the atrium is not required.

• Building fire alarm system in accordance with section 907.2.14

• **Smoke control system accordance with section 909**
Prescriptive Atrium Design cont.

- **Atrium spaces shall be separated from adjacent space by a 1-hour fire barrier**
  - Exception 3: Separation is not required of any three stories (non separated spaces must be accounted for in smoke control system)
- Smoke control equipment must be connected to standby power system
- Interior finish of walls, and ceiling of atrium shall be not less than Class B
- Travel distance through upper levels of atrium reduced to 200 feet
Atrium Separation

• Using 1 Hour Fire barriers to reduce the size of the atrium.

• Components:
  • Gypsum Walls
  • Rated Glass
  • Sprinkled Glass
  • Fire doors
Atrium Separation

Three Story Atrium
Smoke Control *(IBC 909)*

- **Duration** *(IBC 909.4.6)*: Continued operation after the detection of the fire of 20 minutes or 1.5 times the calculated egress time, which ever is less (2015 IBC changes this to which ever is greater.)

- **Design Fire** *(IBC 909.9)*: Fire shall be based on a rational analysis.

- **Exhaust Method** *(IBC 909.8)*: Systems are to be designed per NFPA 92B
  
  - **IBC 909.8.1**: Maintain the smoke layer at least 6’ above any walking surface.
  
  - **NFPA 92B, 4.1.2 (1)**: Maintain a tenable environment within all exit access for the time necessary to allow occupants to reach an exit or area of refuge.
Duration (per ASHRAE Handbook of Smoke Design)

- 20 minutes or one and a half time the calculated egress time, whichever is less (2015 IBC changes this to whichever is greater.)
- Egress Analysis
  - Time to Notification: 30 seconds
  - Pre-Movement: 90 seconds
  - Hydraulic Flow Rate of 296 Occupants Out of Stair 2: 502 seconds
    - Time to controlling element: 190'/275 ft/min + 160' / 106 ft/min = 132 seconds
    - Time through controlling element: 296/48 = 370 seconds
  - Safety Factor: 622 x 0.5 = 311 seconds

**933 Seconds**
Tenability Criteria

• Temperature: 100°C
• CO Concentration: 1,000 ppm
• Visibility: 10 meters
Design Fire (Fuel Sources)

Exhibits
Design Fire Characteristics

- Exhibit (SFPE Handbook, Wood Pallets 1’6” tall)
  - Growth Rate: Ultra-Fast
  - Size: 1,420 kW/m² x 6m² = 8,520 kW
  - Soot Yield: 0.0335
  - CO Yield: 0.0085

<table>
<thead>
<tr>
<th>Fuel Source</th>
<th>Wood (%)</th>
<th>Polyurethane Foam (%)</th>
<th>Wood CO Yield (g/g)</th>
<th>Polyurethane CO Yield (g/g)</th>
<th>Composite CO Yield (g/g)</th>
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</thead>
<tbody>
<tr>
<td>Exhibit</td>
<td>90</td>
<td>10</td>
<td>0.005</td>
<td>0.04</td>
<td>0.0085</td>
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</table>

<table>
<thead>
<tr>
<th>Fuel Source</th>
<th>Wood (%)</th>
<th>Polyurethane Foam (%)</th>
<th>Wood Soot Yield (g/g)</th>
<th>Polyurethane Soot Yield (g/g)</th>
<th>Composite Soot Yield (g/g)</th>
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<tbody>
<tr>
<td>Exhibit</td>
<td>90</td>
<td>10</td>
<td>0.015</td>
<td>0.2</td>
<td>0.0335</td>
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</table>
Design Fire Characteristics

- Sprinkler Activation at 100 seconds, Peak HRR of 1,880 kW
Design Fire Locations
Smoke Control Challenges

Tradition Atrium

The Burke Atrium
NFPA 92 Algebraic Calculations

- Plume is not Axisymmetric
- Layout is similar to plume spillway
- Plugholing occurs at the floor openings

<table>
<thead>
<tr>
<th>Fire Location</th>
<th>Axisymmetric Plume (CFM)</th>
<th>Plume Spillway (CFM)</th>
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<tr>
<td>Level 1</td>
<td>122,105</td>
<td>295,543*</td>
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<tr>
<td>Level 2</td>
<td>53,078</td>
<td>116,341*</td>
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<tr>
<td>Level 3</td>
<td>13,986</td>
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</table>

*Actual Layout is different than Plume Spillway calculation
Smoke Exhaust Vents

<table>
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<tr>
<th>Vent</th>
<th>Orientation</th>
<th>Size</th>
<th>Volume Flow Rate</th>
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<tbody>
<tr>
<td>1</td>
<td>Vertical</td>
<td>4'x40'</td>
<td>75,000 CFM</td>
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<tr>
<td>2</td>
<td>Vertical</td>
<td>4'x40'</td>
<td>75,000 CFM</td>
</tr>
<tr>
<td>3</td>
<td>Vertical</td>
<td>4'x10'</td>
<td>35,000 CFM</td>
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<tr>
<td>4</td>
<td>Vertical</td>
<td>2'x8'</td>
<td>30,000 CFM</td>
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<td>5</td>
<td>Horizontal</td>
<td>2'x8'</td>
<td>30,000 CFM</td>
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<td>6</td>
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<td>Total:</td>
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<td>275,000 CFM</td>
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## Makeup Air Vents

<table>
<thead>
<tr>
<th>Area Designation</th>
<th>Type</th>
<th>Number of Openings</th>
<th>Open Area (sf)</th>
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<tr>
<td>1</td>
<td>Operable Windows</td>
<td>6</td>
<td>48</td>
</tr>
<tr>
<td>2</td>
<td>Operable Windows</td>
<td>4</td>
<td>32</td>
</tr>
<tr>
<td>3</td>
<td>Operable Windows</td>
<td>6</td>
<td>96</td>
</tr>
<tr>
<td>4</td>
<td>Operable Windows</td>
<td>4</td>
<td>64</td>
</tr>
<tr>
<td>5</td>
<td>Operable Doors or Louvers</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>6</td>
<td>Operable Windows</td>
<td>4</td>
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<td>7</td>
<td>Operable Windows</td>
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<td>Total</td>
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FDS Results

3D Soot Smoke View and Velocity Vector Slice at 1,200 seconds
FDS Results, Level 1 Fire Scenario

Visibility at 1,200 Seconds
### FDS Results

<table>
<thead>
<tr>
<th>Fire Scenario</th>
<th>Minimum Tenability Conditions at 6' above floor</th>
<th>Conditions 6' Above Floor Walking Surface at 1,200 (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level 1</strong></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Fire Scenario</td>
<td>Level 1</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>100</td>
<td>25</td>
</tr>
<tr>
<td>CO Concentration (ppm)</td>
<td>1,000</td>
<td>9</td>
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<tr>
<td>Visibility (m)</td>
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<td>14</td>
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<td><strong>Level 2</strong></td>
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<td>Fire Scenario</td>
<td>Level 1</td>
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<td>Temperature (°C)</td>
<td>100</td>
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<tr>
<td>CO Concentration (ppm)</td>
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<td>N/A</td>
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<td>Visibility (m)</td>
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<tr>
<td><strong>Level 3</strong></td>
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<tr>
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<td>Fire Scenario</td>
<td>Level 1</td>
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<td>Temperature (°C)</td>
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</tr>
<tr>
<td>CO Concentration (ppm)</td>
<td>1,000</td>
<td>N/A</td>
</tr>
<tr>
<td>Visibility (m)</td>
<td>10</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Alternate Design
Code Justification (2012 IBC)

• Section 712.1.8: Allows for two story openings when separated from any other openings by construction conforming to shaft enclosures

• Shaft Enclosure Construction Requirements per Section 713:
  • Shaft enclosure walls to be fire barriers having a fire-resistance rating of 1 hour compliant with Section 707.
  • Horizontal assemblies are constructed per Section 711 with a fire-resistance rating no less than required by the building Type.
    • Type IIB does not require rated floors
Separation Between Level 1 and Basement

- 70 Lineal Feet of 1-Hour rated Fire Barrier
- (1) 11’x17’ and (1) 6’x18’ UL-10B 1-Hour Rated Coiling Fire Doors
- 17’/70’ = 24% of aggregate wall width
- Separation is compliant with Section 707
Separation Between Level 2 and Level 3

• Separation is created by non-rated floor and (3) UL-10B 2-Hour Rated Horizontal Shutters (tested in the horizontal orientation)
• Section 711.8 requires floor fire door assemblies used to protect openings in fire-resistance-rated floors to be tested with NFPA 288
• IBC does not address openings in non-rated floors.
Section 104.11 Alternate Design Approach

- NFPA 288
  - Tested with superimposed load
  - Transmission of heat is limited to 250°F
  - Tested under combustion pressure of 0.01 in. wg.

- UL-10B / NFPA 252
  - Limits flaming on the unexposed side of the specimen
  - Hose Stream Test
  - Opening Protective Test
Performance Analysis

• Criteria
  • Tenable conditions maintained through calculated egress time from fire floor
  • Duration: 492 seconds
FDS Model

- Visibility at 100 seconds
  - Untenable conditions at room of origin and exit stair
FDS Model

- Visibility at 234 seconds
  - Untenable conditions at room of origin and all designated exit stairs
FDS Model

- Visibility at 492 seconds
  - Untenable conditions at entire floor, visibility at 0.5 m
Results

Temperature at 492 seconds: 66°C

CO Concentration at 492 seconds: 70 ppm
Results

<table>
<thead>
<tr>
<th></th>
<th>Minimum Tenability Conditions at 6' above floor</th>
<th>Conditions at 6' Above Floor at 492 (s)</th>
<th>Time Tenability Condition is Lost in Room of Fire Origin</th>
<th>Time Tenability Condition is Lost at Floor of Fire Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>100°C</td>
<td>66°C</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>CO Concentration</td>
<td>1,000 (ppm)</td>
<td>70 (ppm)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Visibility</td>
<td>10 (m)</td>
<td>0.5</td>
<td>100 (s)</td>
<td>253 (s)</td>
</tr>
</tbody>
</table>

3D Soot View at 1,200 seconds
Comparison

• Typical Atrium Design
  • Code Compliance: Yes*
  • Performance per FDS Model: Pass
  • Affect on Architectural Design: Extensive redesign required

• Horizontal Separation
  • Code Compliance: Yes*
  • Performance per FDS Model: Fail
  • Effect on Architectural Design: Minimal
Conclusion

• The New Burke Museum is designed to prescriptively meet IBC requirements
• Both atrium designs are code compliant
• The alternate design does not meet a performance criteria
• The Burke’s atrium configuration is not conducive for a smoke control system
Questions?