Construction Warehouse

Culminating Experience in Fire Protection Engineering
FPE 596
Prepared by
Ben Johnson
Construction Warehouse
Waste Treatment and Immobilization Plant (WTP) Project

• U.S. Department of Energy (DOE) Project on the Hanford Site in South-Central Washington State

• Construction Project
  • Non-Reactors Nuclear Facility
  • Vitrification of liquid waste
    • (i.e., transforming liquid waste into glass)

• Project Information
  • http://www.hanfordvitplant.com
Construction Warehouse
Fire Protection Design Criteria

• Original Construction (2002)
  • Uniform Building Code (UBC 1997 Edition) – Type II-N

• Evaluated to
  • International Building Code (IBC 2009 Edition) – Type II-B
Construction Warehouse – Occupancy and Exit Locations
Main Floor

- Main Floor Elevation 0’-0”
  - Footprint: 195 ft x 200 ft
  - Gross Floor Area: 39,000 ft²
- Walled-in Office Area:
  - Footprint: 50 ft x 82 ft
  - Floor Area: 4,100 ft²
  - Occupant Load: 74 persons
- Main Storage Area:
  - Floor Area: 34,900 ft²
  - Occupant Load: 70 persons
Construction Warehouse – Occupancy and Exit Locations
Mezzanine Level

- Mezzanine Elevation 12’-0”
- Walled-in Mezzanine Area:
  - Footprint: 50 ft x 82 ft
  - Floor Area: 4,100 ft²
  - Occupant Load: 65 persons
- Dispersal Mezzanine Elevation 10’-0”
  - Footprint: 15 ft x 20 ft
  - Floor Area: 300 ft²
  - Occupant Load: 1 person
Construction Warehouse – Occupancy and Exit Locations

Second Floor

• Second Floor Elevation 24’-0”
  • Gross Floor Area: 39,000 ft²
  • Operations & Maintenance Offices:
    • Footprint: 150 ft x 98 ft
    • Floor Area: 14,700 ft²
    • Occupant Load: 207 persons
• Second Floor Storage Areas:
  • Floor Area: 24,300 ft²
  • Occupant Load: 51 persons
Construction Warehouse Building Description

• Metal Building
  • Non-combustible, unprotected, structural steel
  • Concrete floors
  • Gypsum board on steel stud interior walls
  • Pre-finished exterior metal wall panels
  • Standing seam metal roof
  • Ceiling and wall insulation with exposed vapor barrier facing

• Installed Fire Systems
  • Automatic fire sprinkler system
  • Fire alarm system
Construction Warehouse Building Description

• Evaluate to International Building Code – 2009 Edition

• “Mixed Use” Occupancy
  • Storage (S-1) and Business (B)

TABLE 508.4
REQUIRED SEPARATION OF OCCUPANCIES (HOURS)

<table>
<thead>
<tr>
<th></th>
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<td></td>
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</tbody>
</table>
Construction Warehouse Building Description

• Evaluate to International Building Code – 2009 Edition
  • Two (2) story structure
  • Roof Ridge (Height) is 45 ft. above grade
  • Main Floor (B) Area = 8,200 ft²; (S-1) Area = 34,900 ft²
Construction Warehouse Building Description

- Ratio of Building Area for each Occupancy
  - Allowable area modified for frontage and automatic sprinkler system installation

<table>
<thead>
<tr>
<th>Floor</th>
<th>Occupancy (ft²)</th>
<th>Allowable Area for Type II-B (ft²)</th>
<th>Ratio</th>
<th>Sum</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>B</td>
<td>S-1</td>
<td>B</td>
<td>S-1</td>
</tr>
<tr>
<td>First</td>
<td>8,200</td>
<td>34,900</td>
<td>86,250</td>
<td>65,625</td>
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<tr>
<td>Mezzanine</td>
<td>24,300</td>
<td>14,700</td>
<td>(Up from 23,000)</td>
<td>(Up from 17,500)</td>
</tr>
<tr>
<td>Second</td>
<td>32,500</td>
<td>48,600</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Construction Warehouse Building Description

• IBC Type II-B - Fire Resistance Rating of Building Elements

**TABLE 601**

<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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<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>A&lt;sup&gt;d&lt;/sup&gt;</td>
<td>B</td>
<td>A&lt;sup&gt;d&lt;/sup&gt;</td>
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<tr>
<td>Primary structural frame&lt;sup&gt;g&lt;/sup&gt; (see Section 202)</td>
<td>3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>1</td>
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<td>Bearing walls</td>
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<tr>
<td>Exterior&lt;sup&gt;f,g&lt;/sup&gt;</td>
<td>3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1</td>
<td>0</td>
<td>2</td>
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<tr>
<td>Interior</td>
<td>3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1</td>
<td>0</td>
<td>1</td>
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<tr>
<td>Nonbearing walls and partitions</td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Exterior</td>
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</tr>
<tr>
<td>Nonbearing walls and partitions&lt;sup&gt;f&lt;/sup&gt;</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Floor construction and secondary members (see Section 202)</td>
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<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Roof construction and secondary members (see Section 202)</td>
<td>1&lt;sub&gt;1/2&lt;/sub&gt;&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1&lt;sub&gt;b,c&lt;/sub&gt;</td>
<td>1&lt;sub&gt;b,c&lt;/sub&gt;</td>
<td>0&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1&lt;sub&gt;b,c&lt;/sub&gt;</td>
</tr>
</tbody>
</table>
Construction Warehouse Building Description

• Fire Barriers
  • Enclosed Exterior Exit Stairwells (4)
    • 2-hour fire rated separation from building interior
    • 1-hour fire rated exterior stairwell wall
    • 1-hour fire rated separation extended 10 ft. on both sides of main building wall

• Elevator Shaft
  • 2-hour fire rated separation

• Elevator Machine Room
  • 2-hour fire rated separation
Construction Warehouse – Water Supply

- **Two (2) redundant fire water storage tanks**
  - Each 350,000 gal. capacity

- **Two (2) redundant Diesel Fire Pumps**
  - Each rated at 2,500 gpm @ 130 psi

- **12 inch diameter underground main**
Construction Warehouse – Water Supply

Graph showing tested water supply at 2329 gpm @ 124 psi and design water supply at 2500 gpm @ 100 psi.
Construction Warehouse – Fire Sprinkler System Design Criteria

Main Floor Storage Area

• Early Suppression Fast Response (ESFR)
  • Group A, unexpanded, exposed, stable plastics
  • Single or double-row racks
  • Maximum Storage Height of 20 ft.
  • Minimum 8 ft. Aisles
  • Gridded system
  • ESFR heads, 205°F, K = 14.0
  • Hose stream allowance – 250 gpm

• Small hose connections provided for first-aid fire fighting and overhaul operations
Construction Warehouse – Fire Sprinkler System Design Criteria

Second Floor

- Control Mode Density/Area (CMDA)
  - Group A, unexpanded, exposed, stable plastics
  - Open Shelf or Solid Piled Storage
  - Maximum Height of 10 ft.
  - Gridded system
  - Design Area: 0.7 gpm / 2,500 ft²
  - Upright Sprinklers, 286°F, K = 16.8
  - Hose stream allowance – 500 gpm

- Small hose connections provided for first-aid fire fighting and overhaul operations
Construction Warehouse – Fire Sprinkler System Design Criteria
Main Floor Office & Mezzanine, Loading Dock (Dry Pipe) & Tool Crib Areas

• General
  • Ordinary Hazard Group 2 Occupancy Classification
  • Reliable Model G
    • Standard Spray Upright (SSU) heads, 212°F & 286°F, K = 5.6
    • Recessed Pendent (REC PEND) heads, 165°F, K = 5.6
    • Horizontal Sidewall (HSWL) heads, 212°F, K = 5.6
  • 500 gpm hose stream allowance
Construction Warehouse – Fire Alarm System

• Building Fire Alarm System
  • Serves the general fire protection needs of the Warehouse
    • Provides for automatic notification of fire to building occupants
    • Automatically shuts down supply ventilation on detection of smoke
    • Monitors fire protection systems for alarm, supervisory and trouble signals

• Protected Premises Fire Alarm System
  • Provides for automatic fire alarm notification to the Fire Department
    • Automatically reports fire alarm, supervisory and trouble signals
    • One-way High Frequency Radio transmitter
Construction Warehouse – Fire Alarm System

- Main Fire Alarm Control Panel (FACP)
  - Notifier® Model No. NFS2-3030
  - Addressable
  - Two (2) Signaling Line Circuits (SLCs)
  - Located in Main Entry
Construction Warehouse – Fire Alarm System

• Initiating Devices – All Initiate a Fire Alarm (Plus Other Functions)
  • Manual Pull Stations at each exit on each floor
  • Photoelectric Smoke Detectors (Elevator Recall Function)
    • Near elevator door on every floor
    • At the top of elevator hoistway
    • In elevator machine room
  • Photoelectric Duct Smoke Detectors (Shutdown AHU Supply Fans)
  • Fixed Heat Detectors (Elevator Shunt Trip)
    • In elevator machine room (w/i 24 inches of sprinkler head)
    • At top of elevator hoistway (w/i 24 inches of sprinkler head)
Construction Warehouse – Fire Alarm System

• Visible and Audible Notification Appliances
  • Four Field Charger Power Supplies
  • 13 Notification Appliance Circuits
  • Visible and Audible Appliances provided
    • Horn/Strobe Units
    • Strobe Units
  • Placement and location in accordance with NFPA 72

• Secondary Power Supplies
  • Fire Alarm Control Panel – 26 A-H battery (17.6 A-H required)
  • Field Charger Power Supplies – 7 A-H battery (1.9 A-H required)
Construction Warehouse
Life Safety Performance Based Design

• Objective
  • Satisfy the following criteria:

  Available Safe Egress Time (ASET) > Required Safe Egress Time (RSET)
Construction Warehouse Life Safety Performance Based Design

Available Safe Egress Time (ASET)

Required Safe Egress Time (RSET)

Margin of Safety (MoS)

Evacuation Time

Pre-Movement Time

Recognition
Interpretation
Reaction/Delay

Detection Time

Notification Time

Ignition Detection Notification Begin Evacuation Complete Tenability Limit
Construction Warehouse – Life Safety Performance Based Design
Detection Time and Notification Time

• Detection Time
  • Assessed by analysis of specific fire scenarios
  • Hand calculations or computer fire model (FDS) results
  • Detection assumed to occur upon the first
    • Smoke detector alarm; or
    • Sprinkler activation

• Notification Time
  • Occupant notification is by Fire Alarm System notification appliances
  • No time delay on sprinkler riser pressure switches
  • Inherent time delay in processing fire alarm signals
  • Notification Time: Assume 30 seconds
Construction Warehouse – Life Safety Performance Based Design

Pre-Movement Time

• Workers Are Trained
  • Recognize and interpret fire notification signals
  • Immediately evacuate in response to a fire alarm
    • Visitors are escorted by a trained worker
  • HOWEVER some workers are expected to delay movement
    • Question fire alarm signal, wait until there is an indication of fire or smoke
    • Investigate, seek out or warn others
    • Collect personal items, shutdown computers and other equipment
    • Attempt to help or rescue coworkers
    • Attempt to put out a fire (e.g., with a fire extinguisher)

• Pre-Movement Time: Assume 60 seconds
Construction Warehouse – Life Safety Performance Based Design

Evacuation Time

- **Egress Analysis**
  - Hand Calculations and Pathfinder Software Egress Model
  - Exterior Stairwells are 2-hour fire-resistive exit enclosures
  - Evacuation time for all occupants pass into a protected stairwell enclosure
  - West Stairwell is most limiting

<table>
<thead>
<tr>
<th>Floor Level</th>
<th>Hand Calc seconds (# occupants)</th>
<th>Pathfinder (SFPE) seconds (# occupants)</th>
<th>Pathfinder (STEERING) seconds (# occupants)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Second Floor</td>
<td>159 seconds (103)</td>
<td>176 seconds (86)</td>
<td>158 seconds (100)</td>
</tr>
<tr>
<td>Office Mezzanine</td>
<td>71 seconds (33)</td>
<td>147 seconds (48)</td>
<td>132 seconds (36)</td>
</tr>
<tr>
<td>Main Floor</td>
<td>Not Calculated (66)</td>
<td>136 seconds (67)</td>
<td>117 seconds (63)</td>
</tr>
</tbody>
</table>

**TOTAL OCCUPANTS USING WEST STAIRWELL**
- 202
- 201
- 209

- **Evacuation Time:** **158 seconds**
Construction Warehouse – Life Safety Performance Based Design
Life Safety Performance Criteria


5.2.2* Performance Criterion.
Any occupant who is not intimate with ignition shall not be exposed to instantaneous or cumulative untenable conditions.
Construction Warehouse – Life Safety Performance Based Design

Tenability Limits

- Tenability limits established to limit
  - Sensory irritation and visual impairment (VISIBILITY)
  - Thermal effects to building occupants (TEMPERATURE)
  - Depression of the central nervous system (CARBON MONOXIDE DOSE)
- Tenability criteria is measured at a level 6 ft. (1.82 m) above the floor

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Limit</th>
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<tbody>
<tr>
<td>Visibility</td>
<td>10 m in Large Open Areas</td>
</tr>
<tr>
<td></td>
<td>3 m in Office Areas</td>
</tr>
<tr>
<td>Carbon Monoxide Dose</td>
<td>0.3 (FED) [10,500 ppm-min]</td>
</tr>
<tr>
<td>Temperature</td>
<td>100°C</td>
</tr>
</tbody>
</table>
Construction Warehouse – Fire Scenario
Main Floor Storage Rack Fire

• Rack Storage Fuel Array
  • Cartons of Unexpanded Polystyrene Cups
    • 1 m x 1 m x 1 m cartons
    • 4 x 4 x 4 carton array
  • Each layer of 4 cartons stored on pallets in an open rack
  • 18 ft. 6 in. ft. height / 24 ft. ceiling
Construction Warehouse – Fire Scenario
Main Floor Storage Rack Fire

• FDS Model
  • Sixteen (16) 1 m\(^2\) Burners – Simulated Fuel Array
    • Burners 1.3 m, 2.8 m, 4.3 m and 5.8 m (Top) above the floor
  • Peak Heat Release Rate
    • “t-cubed” growth / ramp controlled in FDS input
    • Sequenced ignition – 0, 30, 60, 90 seconds
    • 36,500 kW @ 150 seconds (If not controlled by sprinklers)
    • \(Y_5 = 0.074 \text{ g/g} \); \(Y_{CO} = 0.026 \text{ g/g}\)
      • Mass Weighted Average \(Y_5\) and \(Y_{CO}\) (SFPE Hdbk, 3\text{rd Edition}, Table 3-4.14)
      • Corrugated Cardboard and Unexpanded Polystyrene
  • Basis
    • Heskestad Analyses of Rack Storage Tests (SFPE Hdbk, 3\text{rd Edition}, Chapter 3-1, “Heat Release Rates”)
Construction Warehouse – Fire Scenario
Main Floor Storage Rack Fire - Devices

• HVAC
  • (2) 17,500 cfm exhaust fans normally “OFF”, “ON” at 90°F
  • (1) 1,750 cfm exhaust fan always “ON”
  • (4) Open wall vents

• Devices
  • Ceiling temperature detectors 24 ft. above the floor
    • (1) On ceiling at center of fuel array
    • (4) On ceiling equally spaced 4.3 m (10 ft.) from centerline
  • Radiative Flux detectors
    • (8) Trees – 6 detectors spaced 1.2 m (3.9 ft.) vertically
    • Located 2.4 m (8 ft.) and 4.8 m (16 ft.) from each edge of fuel array
Construction Warehouse – Fire Scenario
Main Floor Storage Rack Fire

- Two cases evaluated for this scenario
  - Case 1 - Sprinklers permitted
    - DETACT
      - Sprinkler activation at 60 seconds
      - Fire controlled at 2,592 kW
    - Tenability analysis
    - Evaluate potential for fire spread to adjacent commodities
  - Case 2 - Sprinklers not permitted
    - Growth to 36,500 kW @ 150 seconds
    - Evaluate potential for fire spread to adjacent commodities
Construction Warehouse – Fire Scenario
Main Floor Storage Rack Fire

• Model Results
  • Case 1 – Sprinklers permitted
    • Assess fire dynamics issues:
      • Max. temperature at ceiling in center of plume 180°C (356°F) @ 60 seconds
      • Rad flux rises to approximately 4.0 kW/m² @ 8 ft. and 1.5 kW/m² @ 16 ft. @ 180 seconds
        • Critical Heat Flux (CHF) is 10 kW/m² for corrugated cardboard
Construction Warehouse – Fire Scenario
Main Floor Storage Rack Fire

• Model Results
  • Case 1 – Sprinklers permitted
    • Tenability
      • Visibility Criteria
        • Exceeds 10 m limit
        • Time = 400 seconds
        • 1.82 m above floor
Construction Warehouse – Fire Scenario
Main Floor Storage Rack Fire

• Model Results
  • Case 1 – Sprinklers permitted
    • Tenability
      • Temperature Criteria
        • 100°C not exceeded
          (60°C not exceeded)
        • Time = 480 seconds
        • 1.82 m above floor
Construction Warehouse – Fire Scenario
Main Floor Storage Rack Fire

• Model Results
  • Case 1 – Sprinklers permitted
    • Tenability
      • Carbon Monoxide Dose
        • 100 ppm-min (FED = 0.003)
        • Time = 480 seconds

  • FED of 0.3 is not exceeded

![Carbon Monoxide Dose Graph](image-url)
Construction Warehouse – Fire Scenario
Main Floor Storage Rack Fire

• Model Results
  • Case 1 – Sprinklers permitted
    • Assess ASET vs. RSET
      • ASET = 400 seconds (based on visibility)
      • RSET
        • RSET = 60 + 30 + 60 + 158 = 308 seconds
    • RSET (308 sec) < ASET (400 sec) ➔ GOOD!!
  • Margin of Safety
    • MoS = 400 – 308 = 92 seconds ➔ 30%

\[
\begin{align*}
  t_{\text{detection}} & = 60 \text{ seconds} \\
  t_{\text{notification}} & = 30 \text{ seconds} \\
  t_{\text{pre-movement}} & = 60 \text{ seconds} \\
  t_{\text{evacuation}} & = 158 \text{ seconds}
\end{align*}
\]
Construction Warehouse – Fire Scenario
Main Floor Storage Rack Fire

• Model Results
  • Case 2 – Sprinklers Not Permitted
    • Assess fire dynamics issues:
      • Max. temperature at ceiling in center of plume 877°C (1,611°F) @ 130 seconds

      • 538°C (1,000°F) is exceeded
        • Ceiling / second floor damage is likely

      • Rad flux trends (erratic)
        • Trends to 50 kW/m² over 480 seconds @ 8 ft.
        • Trends to 10 kW/m² over 480 seconds @ 16 ft.

        • Critical Heat Flux (CHF) is 10 kW/m² for corrugated cardboard
        • CHF is exceeded – fire spread to adjacent commodities is predicted
Construction Warehouse – Fire Scenario
Main Floor Storage Rack Fire

• Model Results
  • Conclusions

  • Life Safety performance based design criteria is met

  • Fire sprinklers are essential to survivability of the construction warehouse
    • Without sprinklers
      • Rapid fire growth
      • An uncontrollable fire would result
      • Danger to building occupants and hampered safe egress
      • Spread of fire to adjacent commodities is predicted
      • Ceiling temperature would cause significant damage to the second floor
Construction Warehouse – Fire Scenario
Mezzanine Office Area (Workstation) Fire

• FDS Model
  • Standard 8 ft. x 8 ft. Office Cubicle Fire
  • 1 m² Burner / 32 inches above floor
  • Peak Heat Release Rate
    • “t-squared” growth
    • 6,730 kW @ 530 seconds
    • \( Y_S = 0.037 \text{ g/g} \); \( Y_{CO} = 0.022 \text{ g/g} \)
      • Mass Weighted Average \( Y_S \) and \( Y_{CO} \)
        (SFPE Hdbk, 3rd Edition, Table 3-4.14)
      • Wood, expanded and unexpanded plastic, ABS, Nylon
  • Basis
    • NIST NCSTAR 1-5C, Federal Building and Fire Safety
      Investigation of the World Trade Center Disaster, “Fire Tests of
      Single Office Workstations”
Construction Warehouse – Fire Scenario
Mezzanine Office Area (Workstation) Fire - Devices

• HVAC
  • 400 cfm exhaust fan
  • 2,700 cfm return air
  • 3,100 cfm supply air

• Devices
  • Ceiling Smoke Detector
    • (1) Elevator Lobby
Construction Warehouse – Fire Scenario
Mezzanine Office Area (Workstation) Fire

• Sprinkler Activation
  • DETACT model – 170 seconds
  • Fire controlled at 694 kW

• Smoke Detector Activation
  • Hand calculation – 54 seconds
  • FDS – 62 seconds
Construction Warehouse – Fire Scenario
Mezzanine Office Area (Workstation) Fire

• Model Results
  • Tenability
    • Visibility Criteria
      • Exceeds 3 m limit
      • Time = 130 seconds
      • 1.82 m above floor
Construction Warehouse – Fire Scenario
Mezzanine Office Area (Workstation) Fire

• Model Results
  • Tenability
    • Temperature Criteria
      • 100°C exceeded
      • Time = 140 seconds
      • 1.82 m above floor
Construction Warehouse – Fire Scenario
Mezzanine Office Area (Workstation) Fire

• Model Results
  • Tenability
    • Carbon Monoxide Dose
      • 468 ppm-min (FED = 0.013)
      • Time = 480 seconds

FED of 0.3 is not exceeded
Construction Warehouse – Fire Scenario Mezzanine Office Area (Workstation) Fire

• Assess ASET vs. RSET
  • ASET = 130 seconds (based on visibility)
  • RSET
    • RSET = 54 + 30 + 60 + 158 = 302 seconds
    • RSET (302 sec) > ASET (130 sec) → NO GOOD!!

\[ t_{\text{detection}} = 54 \text{ seconds} \]
\[ t_{\text{notification}} = 30 \text{ seconds} \]
\[ t_{\text{pre-movement}} = 60 \text{ seconds} \]
\[ t_{\text{evacuation}} = 158 \text{ seconds} \]

NOTE: Deficit (RSET – ASET) = 172 seconds
Construction Warehouse – Fire Scenario
Mezzanine Office Area (Workstation) Fire

- Alternatives – (Must make up 172 second deficit)
  1. Replace standard response sprinklers with quick response sprinklers
     • DETACT - Improves sprinkler response by 30 seconds / RSET reduction of 30 seconds
  2. Remove suspended ceiling / replace sprinklers with quick response sprinklers
     • DETACT + FDS – Increases visibility tenability limit (ASET) by 80 seconds
  3. Add a protected exit to mezzanine office area on north exterior wall
     • Pathfinder – Improves time for all building occupants to exit / RSET reduction of 42 seconds
  4. Install mechanical smoke control system
     • FDS – Increases visibility tenability limit (ASET) indefinitely
  5. Remove mezzanine walls – open to main floor storage area
     • Rack Fire Scenario becomes the bounding scenario / MoS = 92 seconds
     • Impact of Rack Fire Scenario on mezzanine occupants must be considered
  6. Do nothing / control number of occupants / control combustible loading
     • Meets prescriptive requirement
     • Refine performance based design analysis
Thank-You!