Storage Protection in the Presence of Horizontal Barriers or Solid Shelving

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Vice President

SUPDET 2018
OUTLINE

- Project Introduction
- Introduction to Horizontal Barriers (with in-rack sprinklers)
- Introduction to Solid Shelving
- Legacy Horizontal Barrier Fire Testing
- Contemporary Horizontal Barrier Fire Testing
- Solid Shelving Fire Testing
- Path Forward
- Questions
Project Objectives
- Identify knowledge gaps within NFPA 13
  - Identify use of horizontal surfaces in storage racks
  - Review currently available test data
  - Substantiate the technical basis for the requirements
- Determine path forward

Tasks Completed
- Literature search
  - Fire Test Data From 1970’s – 2015 Reviewed
MOTIVATION FOR THE PROJECT

- Horizontal Barriers (with in-rack sprinklers)
  - Highest ceiling only rack storage protection scheme
    - Special Application ESFR K=28 sprinklers - 48 ft.
  - What to do for over 48 ft.?

- Solid Shelves
  - Basis for code requirements?
Provisions for the Use of Horizontal Barriers

- NFPA 13 Sections 16.3 and 17.3 - CMDA Sprinkler Protection of Rack Storage over 25 ft., Class I-IV and Plastic Commodities
- NFPA 13 Sections 16.1.2.4 and 17.1.2.9 - Alternate Protection, Class I-IV and Plastic Commodities
HORIZONTAL SURFACES IN STORAGE RACKS

- Horizontal Barriers- Specific protection scheme using in-rack sprinklers
- Protection Option for > 25 ft. tall storage
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- Gas velocities increase with height (Ingason)
- Horizontal barriers prevent the flame front from moving past the in-rack sprinkler prior to the sprinkler’s activation

\[
M = \text{Mass of the fusible link} \\
C_p = \text{Thermal capacity of the fusible link} \\
A_s = \text{Area of the fusible link} \\
T_g = \text{Temperature of the ceiling jet} \\
u_g = \text{Velocity of the ceiling jet}
\]
Provisions for the Protection of Solid Shelves
- NFPA 13 Sections 16.1.6 and 17.1.5 - Class I-IV and Plastic Commodities
- Protection of solid shelf racks with ESFR sprinklers is prohibited
Solid Shelves- Used for storage convenience. Derogatory effect on fire sprinkler performance.
LEGACY HORIZONTAL BARRIER FIRE TESTING

- Approximately 20 Tests, 1971-1972
- Standard Class II Commodity
- 30 ft. Storage, 40 ft. Ceiling
- Horizontal Barriers Located at 3rd and 6th Tiers.

- Ceiling Sprinkler Design - 0.30 gpm /sq.ft.
- K=5.6, 280°F, RTI >80(m-s)½
- 10 ft. x 10 ft. Spacing
- In-rack Sprinklers Characteristics - Same as Ceiling Sprinklers, Located Under Each Barrier
- Rack Sprinkler Design - 30 psi design
## LEGACY HORIZONTAL BARRIER FIRE TESTING

<table>
<thead>
<tr>
<th>Test No.</th>
<th>In-rack Sprinkler Arrangement</th>
<th>Horizontal Barrier Location</th>
<th>No. Ceiling Sprinklers Activated</th>
<th>No. In-Rack Sprinklers Activated</th>
<th>Damage (No. of Boxes)</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>121</td>
<td>At 3&lt;sup&gt;rd&lt;/sup&gt; and 6&lt;sup&gt;th&lt;/sup&gt; tiers. 8 ft. horizontally in longitudinal flue space. No face sprinklers.</td>
<td>At 3&lt;sup&gt;rd&lt;/sup&gt; and 6&lt;sup&gt;th&lt;/sup&gt; tier</td>
<td>0</td>
<td>2</td>
<td>8</td>
<td>Passed</td>
</tr>
<tr>
<td>126</td>
<td>Same</td>
<td>Same</td>
<td>0</td>
<td>3</td>
<td>13</td>
<td>Passed</td>
</tr>
<tr>
<td>127</td>
<td>Same</td>
<td>Same</td>
<td>0</td>
<td>4</td>
<td>21</td>
<td>Passed</td>
</tr>
<tr>
<td>128</td>
<td>At the 3&lt;sup&gt;rd&lt;/sup&gt; and 5&lt;sup&gt;th&lt;/sup&gt; tiers. 8 ft. horizontally in longitudinal flue space. No face sprinklers.</td>
<td>No horizontal barriers provided</td>
<td>2</td>
<td>4</td>
<td>48</td>
<td>Failed</td>
</tr>
</tbody>
</table>
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CHRONOLOGY OF NFPA 13 HORIZONTAL BARRIER DESIGN REQUIREMENTS

- NFPA 231C, 1972 edition - No requirements for > 25 ft. storage
- Current Edition, NFPA 13, Similar Requirements
- Based Upon the Legacy Testing
Concerns

- Limited testing for Class III-IV and Plastic Commodities
- K=5.6 orifice sprinklers were used
# ALTERNATE PROTECTION SCHEME

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Rack Type</th>
<th>Horizontal Barrier Location</th>
<th>In-rack Sprinkler Location</th>
<th>In-rack Sprinkler Details</th>
<th>In-rack Sprinkler Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I-IV and Plastics</td>
<td>Open</td>
<td>12 ft. max vertically</td>
<td>Under the barriers, at each rack upright in the longitudinal flue space and at the face of the rack and at the mid-bay of each rack bay.</td>
<td>Min K=8.0, Quick Response</td>
<td>6 sprinklers at minimum flow of 60 gpm.</td>
</tr>
<tr>
<td>Class I-IV and Plastics</td>
<td>Solid Shelf</td>
<td>Every tier vertically</td>
<td>Same</td>
<td>Same</td>
<td>Same</td>
</tr>
</tbody>
</table>

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ALTERNATE PROTECTION SCHEME

NFPA 16.1.2.4

FIGURE 16.1.2.4.2(A) Alternative Protection for Double-Row Racks.
Origin of Requirements
- FM Global sponsored combustible liquid fire testing
- Adopted in FM Data Sheet 7-29 for protection of flammable liquids
- Adopted in NFPA 30 for flammable liquids
- Adopted in FM Data Sheet 8-9 for protection of Class I-IV and plastics
- Adopted by NFPA 13, 2013 edition (?)
  - Sections 16.1.2.4 and 17.1.2.9
- Excellent correlation with fire test data
CONTEMPORARY USE OF HORIZONTAL BARRIER IN-RACK PROTECTION SCHEMES

- Renaissance in the use of horizontal barriers/in-rack sprinkler protection schemes
  - Taller storage facilities, such as retail fulfillment centers
  - New design approaches
    - Large K factor in-rack sprinklers
- Advantages to this design approach
  - The sprinklers are not affected by ceiling construction slope or obstructions
  - Reduced water demand compared to ceiling sprinkler design
Test Array

- Standard Group A commodity
- 43 ft. storage, 48 ft. ceiling,
- Wood barrier at 30 ft. (3/8 in. plywood)
- Double row racks, 6 in longitudinal and transverse flue space
- 4 ft. aisles
- In-rack sprinklers K=25.2 extended coverage pendent sprinklers
- 30 psi nominal discharge pressure
- In-rack sprinkler layout 8 ft. 3 in centered on rack bays
- Ceiling sprinkler spacing 10 ft. x 10 ft. (K=25.2 Extended Coverage Pendent)
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Plywood Barrier  In-Rack Sprinklers

ELEVATION - FRONT VIEW
ALL DIMENSIONS NOMINAL

*SPRINKLER LOCATIONS
3/8 inch thick plywood spanning both rack uprights, flush with aisle facing beams.

3 inch schedule 40 piping to 1-1/2 inch three bolt tee to 1-1/2 inch Tee of 3/4 inch reducing elbow to sprinkler.

6 in.

3 in.

12 inches
EXAMPLE: TEST NO. 4 AUGUST 7, 2015

Open space between rack uprights
### Results

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of Test, minutes</td>
<td>35:00</td>
</tr>
<tr>
<td>First Sprinkler Operation Time min:sec</td>
<td>4:28</td>
</tr>
<tr>
<td>Last Sprinkler Operation Time min:sec</td>
<td>25:27</td>
</tr>
<tr>
<td>Number of Operated Sprinklers</td>
<td>2</td>
</tr>
<tr>
<td>Maximum 1 minute Average Steel Temperature at Ceiling Above Ignition °F</td>
<td>107</td>
</tr>
<tr>
<td>Fire Travel to Extremities of Test Array</td>
<td>No</td>
</tr>
<tr>
<td>Ignition of Target Array min:sec</td>
<td>No</td>
</tr>
</tbody>
</table>
RESULTS

Fire Damage

- Horizontal fire travel limited to center 2 bays of ignition array
- Vertical fire travel limited to first 4 tiers above ignition

Initial Phase of Fire Growth

Later Phase of Fire Growth
SOLID SHELF FIRE TESTING

- Approximately 4 Tests, 1967
- Tests 98 and 147 analyzed
- Standard Class II Commodity
- 20 ft. Storage, 30 ft. Ceiling
- Ceiling Sprinkler Design 0.30-0.45 gpm /sq.ft.
- K=5.6, 280°F, RTI >80(m-s)½
- 10 ft. x 10 ft. Spacing
- Ignition in the transverse flue space offset from the aisle
SOLID SHELF FIRE TESTING
## Test Results

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Solid Shelf Size</th>
<th>Flue Spaces</th>
<th>Aisle</th>
<th>Sprinkler Density (gpm/sq. ft.)</th>
<th>First Sprinkler Activation Time</th>
<th>No. Sprinklers Operated</th>
</tr>
</thead>
<tbody>
<tr>
<td>98</td>
<td>7.5 ft. x 50 ft. (375 sq. ft.)</td>
<td>0 in.</td>
<td>8 ft.</td>
<td>Provided-0.30 Required-0.37</td>
<td>4:18</td>
<td>58</td>
</tr>
<tr>
<td>66 Baseline Test</td>
<td>None</td>
<td>6 in. Longitudinal and Transverse</td>
<td>8 ft.</td>
<td>Provided-0.30 Required-0.37</td>
<td>3:11</td>
<td>48</td>
</tr>
</tbody>
</table>
## RESULTS

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Commodity Consumed Main Rack (%)</th>
<th>Commodity Consumed East Target (%)</th>
<th>Commodity Consumed West Target (%)</th>
<th>Max. Ceiling Air Temperatures (°F)</th>
<th>Bar Joist Steel Temperature (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>98</td>
<td>100</td>
<td>0</td>
<td>18</td>
<td>1140-1:56</td>
<td>170</td>
</tr>
<tr>
<td>66</td>
<td>55</td>
<td>0</td>
<td>0</td>
<td>1630-19:50</td>
<td>180</td>
</tr>
</tbody>
</table>
RESULTS

Baseline Fire Damage

Test 98 Fire Damage
### RESULTS

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Solid Shelf Size</th>
<th>Flues Space</th>
<th>Aisle</th>
<th>Sprinkler Density (gpm/sq.ft.)</th>
<th>First Sprinkler Activation Time</th>
<th>No. Sprinklers Operated</th>
</tr>
</thead>
<tbody>
<tr>
<td>147</td>
<td>3.5 ft. x 7.75 ft.</td>
<td>6 in. Longitudinal and Transverse</td>
<td>4</td>
<td>Provided-0.45 Required-0.44</td>
<td>1:23</td>
<td>47</td>
</tr>
<tr>
<td>89 Baseline Test</td>
<td>Slave pallets, beneath the pallets (42 in. x 42 in)</td>
<td>6 in. Longitudinal and Transverse</td>
<td>4</td>
<td>Provided-0.45 Required-0.44</td>
<td>2:57</td>
<td>7</td>
</tr>
</tbody>
</table>
## RESULTS

### Test Results

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Commodity Consumed Main Rack (%)</th>
<th>Commodity Consumed East Target (%)</th>
<th>Commodity Consumed West Target (%)</th>
<th>Max. Ceiling Air Temperatures (°F)</th>
<th>Bar Joist Steel Temperature (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>147</td>
<td>91</td>
<td>74</td>
<td>0</td>
<td>1545-6:00</td>
<td>175</td>
</tr>
<tr>
<td>89</td>
<td>30</td>
<td>0</td>
<td>0</td>
<td>925- ?</td>
<td>105</td>
</tr>
</tbody>
</table>
RESULTS

Baseline Fire Damage

Test 147 Fire Damage
Hypothesis– The application of adequate water flux to the rack face and down thru the transverse/longitudinal flue spaces may limit horizontal and vertical spread of the fire, despite the presence of solid shelves

- Improved performance of modern sprinklers, especially ESFR sprinklers (K= 14.0-25.0)
  - Water flux comparison- 0.30 gpm/sq. ft. vs 1.0 gpm/sq.ft.
  - Sprinkler response – Much quicker (ESFR sprinklers)
## SPRINKLER ORIFICE SIZE COMPARISON

### NFPA 13 K Factor Requirements

<table>
<thead>
<tr>
<th>Design Density (gpm/sq. ft.)</th>
<th>Minimum Sprinkler K Factor (gpm/(psi) $^{1/2}$)</th>
<th>Orifice Size (Inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\leq 0.20$</td>
<td>5.6</td>
<td>0.5</td>
</tr>
<tr>
<td>$&gt; 0.20-0.34$</td>
<td>$\geq 8.0$</td>
<td>$\geq 0.53$</td>
</tr>
<tr>
<td>$&gt; 0.34$</td>
<td>$\geq 11.2$</td>
<td>$\geq 0.64$</td>
</tr>
</tbody>
</table>
SOLID SHELF RESEARCH DIRECTION

No. Sprinklers Operating/No. Pallets Consumed

Orifice Size vs No. Operating Sprinklers

Orifice Size Vs No. Pallets Consumed
 Test the hypothesis
   Fire test parameters
    – Commodity
    – Rack array, reduction in length to reduce test costs (30 ft. vs 50 ft.)
    – Ceiling height, start at 20 ft., then increase height
   Sprinkler parameters
    – ESFR, most commonly used sprinklers
    – Use K factor which allows broad application of findings
   Solid Shelving Details
    – 32 sq. ft. with longitudinal and transverse flues spaces at rack uprights.
    – Shelving on every tier of storage
**SOLID SHELF FIRE TESTING APPROACH**

- **Potential Test Sequence**
  - **Test 1**
    - Standard cartoned unexpanded plastic
    - 20 ft. storage 30 ft. ceiling
    - K=17 ESFR sprinklers
    - Reduced rack array
  - **Test 2 (if Test 1 is successful)**
    - Standard cartoned unexpanded plastic
    - 30 ft. storage 40 ft. ceiling
    - K=17 ESFR sprinklers
    - Reduced rack array
Horizontal Barriers with In-rack Sprinklers

- The legacy fire testing completed included primarily with Class II commodity
- Strong correlation between NFPA 13 requirements and the fire testing work
- The ability of these protection schemes to protect Class IV and plastic commodities should be explored

Solid Shelving

- Limited testing
- Out of date sprinkler technology
- Modern sprinkler technology has superior performance
- Recommend additional research effort
QUESTIONS?

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