Protection of Rack Stored Exposed Expanded Group A Plastics With ESFR Sprinklers and Vertical Barriers

9th-10th in a Series of Ten Tests

Final Report

Prepared by:

UL LLC

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Exposed expanded Group A plastics rack storage represents a growing challenge for sprinkler protection in warehouses. This report presents the ninth and tenth of ten full scale fire tests to explore the effectiveness of the combination of an innovative vertical barrier protection feature with ceiling only sprinkler protection.

The Research Foundation expresses gratitude to the report author UL LLC. The Research Foundation appreciates the guidance provided by the Project Technical Panelists, the funding provided by the project sponsors, and all others that contributed to this research effort. Thanks are also expressed to the National Fire Protection Association (NFPA) for providing the project funding through the NFPA Annual Code Fund.

The content, opinions and conclusions contained in this report are solely those of the authors.

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**Keywords:** group A plastics, sprinklers, vertical barriers, test
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Property Insurance Research Group
Tyco
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PROTECTION OF RACK STORED EXPOSED EXPANDED GROUP A PLASTICS WITH ESFR SPRINKLERS AND VERTICAL BARRIERS
TEST 9 and 10

Prepared by
UL LLC

for
The Fire Protection Research Foundation

Project 4786573963, NC5756
Project 4786574396, NC1838

Issued: November 11, 2014
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Executive Summary

This report describes two large scale fire tests that were conducted to develop data relative to the level of protection provided by ESFR sprinklers installed to protect double-row rack arrangements of exposed, expanded Group A plastics stored 20 and 25 ft. high under a 30 ft. ceiling with vertical barriers installed within the primary rack storage array. The test described in this report was in addition to the test series conducted as a part of the Fire Protection Research Foundation’s exposed expanded Group A plastics research project described in report entitled *Protection of Rack Stored Exposed Expanded Group A Plastics with ESFR Sprinklers and Vertical Barriers* dated November, 2012 (Tests 1 – 6), June 28, 2013 (Test 7) and June 22, 2014 (Test 8).

The commodity used in the investigation consisted of expanded polystyrene meat trays, stored in plastic bags and resting on two-way entry, hardwood pallets. The nominal external dimensions of the commodity was 37 inches wide by 45 inches deep by 40 inches tall resting on a nominal 4-1/2 inch tall, 42 by 42 inch hardwood pallet.

The vertical barriers installed within the primary rack storage array were intended to inhibit the horizontal fire travel and reduce the potential for the fire to travel to the extremities of the test array. The tests were conducted with plywood vertical barriers installed 16 ft. on center. No transverse flue spaces were blocked during the tests. The tests were conducted with an 8 ft. aisle between the main array and the target commodity located on both sides of the main array.

For the tests, nominal K=25.2 gpm/psig$^{1/2}$ pendent ESFR sprinklers were installed to protect the test commodity. The ignition was located at the base of the array, under one sprinkler for Test 9 and between two sprinklers on the same branch line for Test 10. The ignition location was offset in the transverse flue space in both tests. A constant flowing pressure of a nominal 30 psig was provided for the tests.

During Test 9, a total of 7 sprinklers operated. The fire travelled beyond the vertical barrier east of the ignition location, but did not spread to the ends of the main test array. Neither target array was ignited during Test 9.

During Test 10, a total of 7 sprinklers operated. The fire was contained within the vertical barriers except for incidental damage just outside the barrier to the West end of the array. Neither target array ignited during Test 10.

Where breaching of the vertical barriers occurred during the tests, it was observed that the fire travelled around the barrier at the aisle face where the commodity extended approximately 4 inches beyond the face of the uprights or vertical barriers. No through penetrations of the plywood barriers were seen.

A summary of the test parameters and results for the test is provided in Table E1.
Table E 1. Test Parameters and Results

<table>
<thead>
<tr>
<th>Fire Test Number</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Date</td>
<td>October 28, 2014</td>
<td>October 30, 2014</td>
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**Test Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test 9 Details</th>
<th>Test 10 Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage Type</td>
<td>Double Row Rack</td>
<td></td>
</tr>
<tr>
<td>Commodity Type</td>
<td>Exposed Expanded Group A Plastic (Bagged Meat Trays on Hardwood Pallets)</td>
<td></td>
</tr>
<tr>
<td>Pallet Type</td>
<td>2 way entry, stringer, hardwood</td>
<td></td>
</tr>
<tr>
<td>Vertical Barriers</td>
<td>16 ft. on center - Main Array (3/8 in. plywood)</td>
<td>None</td>
</tr>
<tr>
<td>Horizontal Blocking of Transverse Flues in Main Array (non-combustible)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length of Main Storage Array, ft.</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>Nominal Storage Height, ft.</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>Ceiling Height, ft.</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Nominal Clearance, ft.</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Aisle Width, ft.</td>
<td>8</td>
<td></td>
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<tr>
<td>Ignition Location</td>
<td>Under One Sprinkler (offset)</td>
<td>Between Two Sprinklers (offset)</td>
</tr>
<tr>
<td>Sprinkler Systems</td>
<td>Ceiling Only (no in-rack sprinklers)</td>
<td></td>
</tr>
<tr>
<td>Sprinkler Orientation</td>
<td>Pendent</td>
<td></td>
</tr>
<tr>
<td>Deflector to Ceiling, in.</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Sprinkler Spacing, sprinkler by branchline ft. by ft.</td>
<td>10 by 10</td>
<td></td>
</tr>
<tr>
<td>Temperature Rating, F</td>
<td>214</td>
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<tr>
<td>Sprinkler Type</td>
<td>ESFR</td>
<td></td>
</tr>
<tr>
<td>Nominal Sprinkler Discharge Coefficient K, gpm/psig (^{0.5})</td>
<td>25.2</td>
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<tr>
<td>Nominal Discharge Density, gpm/ft(^2)</td>
<td>1.38</td>
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<tr>
<td>Nominal Discharge Pressure, psig</td>
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**Test Results**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test 9 Details</th>
<th>Test 10 Details</th>
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<tbody>
<tr>
<td>Length of Test, minutes</td>
<td>31</td>
<td>31</td>
</tr>
<tr>
<td>First Sprinkler Operation Time, min:sec</td>
<td>0:47</td>
<td>0:53</td>
</tr>
<tr>
<td>Last Sprinkler Operation Time, min:sec</td>
<td>1:24</td>
<td>1:14</td>
</tr>
<tr>
<td>Number of Operated Sprinklers</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Peak Gas Temperature at Ceiling Above Ignition, °F</td>
<td>204</td>
<td>990</td>
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<tr>
<td>Maximum 1 minute Average Gas Temperature at Ceiling Above Ignition, °F</td>
<td>138</td>
<td>477</td>
</tr>
<tr>
<td>Peak Steel Temperature at Ceiling Above Ignition, °F</td>
<td>114</td>
<td>149</td>
</tr>
<tr>
<td>Maximum 1 minute Average Steel Temperature at Ceiling Above Ignition, °F</td>
<td>112</td>
<td>144</td>
</tr>
<tr>
<td>Fire Travel to Extremities of Test Array</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
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<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>°C</td>
<td>degrees Centigrade</td>
</tr>
<tr>
<td>°F</td>
<td>degrees Fahrenheit</td>
</tr>
<tr>
<td>psig</td>
<td>unit of pressure; pounds per square inch gauge</td>
</tr>
<tr>
<td>gpm</td>
<td>gallons per minute</td>
</tr>
<tr>
<td>ft.</td>
<td>foot</td>
</tr>
<tr>
<td>in.</td>
<td>inch</td>
</tr>
<tr>
<td>mm</td>
<td>millimeter</td>
</tr>
<tr>
<td>cm</td>
<td>centimeter</td>
</tr>
<tr>
<td>m</td>
<td>meter</td>
</tr>
<tr>
<td>RTI</td>
<td>Response time index</td>
</tr>
<tr>
<td>Lbₘ</td>
<td>Pounds mass</td>
</tr>
<tr>
<td>dno</td>
<td>Did not operate</td>
</tr>
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</table>
1. INTRODUCTION

This report describes a Special Services Investigation conducted for the Fire Protection Research Foundation in accordance with the test method described herein.

The sole purpose of this Special Services Investigation was to develop large scale fire test data on ceiling only, ESFR fire sprinkler systems protecting rack stored exposed expanded Group A plastic commodity. Vertical plywood barriers were employed strategically within the main test array to mitigate lateral fire spread.

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Investigations normally conducted by UL LLC involve Classification, Listing or Recognition and Follow-Up Services of proprietary products. However, UL LLC does conduct investigations without Classification, Listing or Recognition in Follow-Up Service when a need for test data in the interest of public safety has been indicated. Such investigations do not result in specific conclusions, nor any form of Recognition, Listing or Classification of the products involved. It is on this basis that UL LLC undertook the Special Services Investigation reported herein.

The issuance of this Report in no way implies Listing, Classification or Recognition by UL LLC for the storage configuration.

2. TEST FACILITY

The fire tests were conducted at UL's large-scale fire test facility located in Northbrook, Illinois.

2.1 Large-Scale Fire Test Building

The large-scale fire test building used for this investigation houses four fire test areas that are used to develop data on the fire growth and fire suppression characteristics of commodities, as well as the fire suppression characteristics of automatic water sprinkler systems. A schematic of the test facility is shown in Figure 1.
2.2 Large-Scale Fire Test Facility

The test was conducted in the 120 by 120-ft. main fire test cell that is equipped with a 100 by 100-ft adjustable height ceiling. The 10-ft perimeter between the moveable ceiling and the walls of the test room provides for the simulation of a larger warehouse by not allowing the smoke and heat layer from the test to be contained.

The center of the floor of the test facility is 100 by 100-ft., is smooth and flat and is surrounded with a grated drainage trench to insure adequate water drainage from the test area. The water from the suppression system is collected, contained and filtered through a nominal 180,000-gallon water treatment system.

The large-scale test cell used in this investigation is equipped with an exhaust system capable of a maximum flow of 60,000 cubic feet per minute through a smoke abatement system. Combustion air was provided through four inlet ducts positioned along the wall of the test facility. The combustion air was released into the room approximately 10-ft above the floor level through straightening screens. This ventilation arrangement provided adequate air so that the fire growth occurs naturally.

All products of combustion from the tests were contained within the test facility and processed through a regenerative thermal oxidizing system.
3. EQUIPMENT

3.1 Automatic Sprinkler System

A wet pipe automatic sprinkler system was positioned below the adjustable smooth, flat non-combustible ceiling and pressure controlled to provide a specific applied nominal flowing pressure as defined below.

The sprinklers were supplied through a looped piping system consisting of 2 ½-in. diameter, schedule 40 branch lines. The piping system was supplied by a variable speed pump capable of supplying an adequate pressure and flow to maintain the required applied flowing pressure throughout the course of the test.

3.1.1 Sprinkler

The automatic sprinkler system consisted of pendent ESFR sprinklers having a nominal K-Factor of 25.2 gpm/psig^{0.5} in the 214°F temperature rating with a 1 inch NPT inlet thread. The sprinklers were installed on 10 ft. branch line by 10 ft. sprinkler spacing, with the sprinkler deflector located nominally 14 in. below the moveable ceiling. A photograph of the sprinkler used is shown in Figure 2. A schematic of the sprinkler numbering system is shown in Figure 3 and Figure 4 for Test 9 and 10 respectively.

![Figure 2 Test Sprinkler Photos](image-url)
10 ft. (Typ.)

Ignition location: Centered under one sprinkler, offset in transverse flue space.

Figure 3 Test 9 Arrangement and Sprinkler Numbering System
Figure 4  Test 10 Arrangement and Sprinkler Numbering System

Ignition location: Centered under one sprinkler, offset in transverse flue space.
3.2  Air Temperature Instrumentation

3.2.1  Air Temperature Near Sprinklers
The air temperature adjacent to each sprinkler was measured with a 0.0625-in.diameter inconel sheathed Type K thermocouple.

3.2.2  Air Temperature Above Ignition
The ceiling gas temperature above ignition was measured using the same type of thermocouples as stated in 3.2.1. The gas temperature was measured adjacent to the steel beam described in 3.3, with the thermocouples, positioned 6, 12, and 18 inches below the ceiling. The three thermocouples were positioned near the ends and centered on the steel beam.

3.3  Steel Beam Temperature
A nominal 4 ft. long by 2 in. wide by 2 in. high steel angle was mounted below the ceiling above the ignition location of the test array. The temperature of the steel beam was measured with five Type K thermocouples embedded within the beam. The thermocouples were equally spaced within the beam.

3.4  Video
Six video cameras were used to record the test. Four cameras were centered on each wall of the test cell. One camera was positioned on the observation balcony in the North East corner of the laboratory, and one camera was positioned on the test room floor to capture critical events. In addition, an infrared camera was used to record the events from the South East corner of the test array.

3.5  Data Collection
All data was collected using an electronic data acquisition system at a one-second-scan rate.
4. **EXPOSED EXPANDED GROUP A PLASTIC COMMODITY**

4.1 **Components**

4.1.1 **Pallets**

The fire test series was conducted using two way pallets as a base for the commodity. The kiln dried 2-way entry white oak hard wood pallets had outside dimensions of 42 by 42 by 4-1/2 in. tall. Photographs of the pallets are shown in Figure 5.

![Figure 5 2-Way Entry, Hard Wood Pallet](image-url)
4.1.2 Meat Trays

The meat trays used in the exposed expanded Group A commodities were manufactured from expanded polystyrene. A grouping of meat trays were randomly selected and measured dimensionally and by weight to determine average values. The results are presented in Table 1. Photographs of a representative meat tray are shown in Figure 6.

<table>
<thead>
<tr>
<th>Meat Tray Description</th>
<th>Average Length (in.)</th>
<th>Average Width (in.)</th>
<th>Average Height (in.)</th>
<th>Average Mass (grams)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expanded Polystyrene</td>
<td>12-1/4</td>
<td>10-1/8</td>
<td>1-1/8</td>
<td>11.6</td>
</tr>
</tbody>
</table>

Table 1  Meat Tray Details

Figure 6  Front and Back View of Meat Tray
4.2 Commodity Description

4.2.1 Exposed Expanded Group A Plastic

The exposed expanded Group A plastic commodity consisted of eight, two sleeve bundles, each weighing an average of 6.5 lb. and containing approximately 260 expanded polystyrene meat trays. Each bundle was divided into two groups and contained in an outer plastic bag. The bundles were shrink wrapped around the sides to provide a more stable stored commodity arrangement. The nominal external dimensions of the commodity was 37 inches wide by 45 inches deep by 40 inches tall resting on a nominal 4-1/2 inch tall, 42 by 42 inch hardwood pallet.

The commodity is shown in Figure 7.

![Exposed Expanded Group A Plastic Commodity](image)

Figure 7 Exposed Expanded Group A Plastic Commodity

The test results apply only to the samples tested.
5. **STRUCTURE**

5.1 **Racking**

The racking configuration used in the investigation incorporated welded steel uprights and beams. The component uprights and beams are shown in Figure 8.

The welded uprights measured 36 inches wide, and the steel beams measured 8 ft. long.

![Component Uprights and Beams with Plywood Vertical Barriers](image-url)
5.2 Vertical Barriers

The rack storage arrangement incorporated vertical barriers to assist in the control of lateral fire spread.

The barriers terminated 4 inches from the test room floor as shown in Figure 9 through Figure 13. The uppermost termination of the barriers occurred at the maximum height of racking which was approximately 21 ft. tall for Test 9 and in line with the top of the commodity which was approximately 25 ft. tall for Test 10.

The combustible barriers were constructed from nominal 3/8 inch thick plywood sheathing as shown in Figure 9. Both the gaps between the individual rack upright members as well as the gap between the two separate uprights of the double row rack array were covered as shown in Figure 10. The plywood was fastened to the steel uprights with metal, self-tapping screws.
Figure 10  Combustible Vertical Barrier Detail (Test 10 in picture below)
5.3 Transverse Flue Blocking

No transverse flue space blocking was used in this test.

6. TEST ARRAY CONFIGURATION

6.1 Rack Array and Plan View

The racking system used is considered double row racking in accordance with NFPA 13.

Each bay of the racking system was filled with two pallet loads of the test commodity as defined in section 4.2.

Figure 11 shows the details of the plan view of the rack array for both tests. Figure 12 and Figure 13 show the detail of the elevation view for Test 9 and Test 10 respectively.
Figure 11 Test Array Plan View - General

- Plywood Vertical Barriers at Uprights Shown
- 8 ft. aisle
- 6 in. longitudinal flue space
- Ignition - 2 half standard igniters
- Exposed Expanded Group A Plastic (typical)
6.2 Ceiling Height and Clearance

The test laboratory’s moveable ceiling was positioned at 30 ft. from the test room floor as shown in Figure 12 and Figure 13, which provided for a nominal 10 ft. and 5 ft. clearance between the ceiling and the top of the commodity for Test 9 and 10 respectively.

A 14 inch pendent sprinkler deflector to ceiling clearance was used in both tests.

Figure 12 Test 9 - Elevation View of Main Test Array from the North
Figure 13  Test 10 - Elevation View of Main Test Array from the North
6.3 Test Arrangement

The steel racks were loaded with the commodity as defined in Section 4. The loading arrangement is as shown in Figure 11 through Figure 13.

Photographs of the test arrangements are shown in Figure 14 through Figure 17.

Limited length target arrays were established across a nominal 8 ft. aisle space as shown in Figure 3, Figure 4 and Figure 11.
Figure 14   Test 9 - Elevation View from the South East
Figure 15  Test 9 - Elevation View from the North (with the target array commodity)
Figure 16    Test 10 - Elevation View from the South East
Figure 17       Test 10 - Elevation View from the North (with the target array commodity)
6.4 Ignition

Ignition was accomplished using two half igniters.

The igniters were constructed from a 3-in. diameter by 3-in. long cellulosic bundle soaked with 4 fluid ounces of gasoline and wrapped in a polyethylene bag. The igniters were positioned adjacent to the expanded plastic commodity, on top of the pallet in the transverse flue space, at the center of the North main rack array as shown in Figure 3, Figure 4 and Figure 18.

The main rack array was positioned such the geometric center of the central transverse and longitudinal flue spaces was directly under one sprinkler for Test 9 and between two sprinklers on the same branch line for Test 10. A photograph illustrating the ignition source is provided in Figure 18.

![Two Half Igniters](image)

Figure 18 View Showing Igniters in North Main Transverse Flue Space at Base of Array (Test 9 shown as representative of both tests)
7. TEST METHOD

7.1 Test Procedure

The test procedure consisted of the following steps:

1. A detailed camera assessment of the commodity and vertical barrier positions within the racking array was documented prior to test.
2. The igniters were placed as discussed previously in the “Ignition” section above.
3. The data acquisition system was started upon ignition of the igniters.
4. The test pressures for the sprinkler system was established by adjusting the system’s fire pump speed.
5. The test proceeded for 30 minutes after the operation of the first sprinkler, rounded up to the nearest whole minute.
6. After test termination, fire fighters manually fought the fire until it was extinguished.
7. Detailed photographs of the commodity damage within the racking array were made after the test had been completed. See Appendix B for photographs of the damage assessment.

7.2 Fire Test Photographs

The initial stage of the fire test is shown in Figure 19 and Figure 20 for Tests 9 and 10 respectively.
Figure 19  Test 9 - Fire Test Photo During Early Stage of Test
Figure 20  Test 10 - Fire Test Photo During Early Stage of Test
8. RESULTS AND DISCUSSION

The fire tests incorporating rack storage of exposed expanded Group A plastic was conducted at UL LLC in Northbrook, IL on Tuesday, October 28th and Thursday October 30th, 2014 for Tests 9 and 10 respectively. The following is a summary of the resulting data.

8.1 Number of Operating Sprinklers:

Figure 21 and Figure 22 illustrates the sprinkler operation sequence for Tests 9 and 10 respectively.

Figure 21 Test 9 - Operation Sequence of Sprinklers (minutes:seconds)

Ignition location: Centered under one sprinkler, offset in transverse flue space.

Figure 22 Test 10 - Operation Sequence of Sprinklers (minutes:seconds)
Appendix A provides the data for the test 9. Appendix B provides the data for test 10.

The individual sprinkler temperature profiles are presented in Figures 1 - 8.

8.2 Temperature Results:

Figure 22 Test 10 - Operation Sequence of Sprinklers (minutes:seconds)
Steel beam and gas temperatures above ignition are presented in Figures 9 and 10.

Sprinkler system flowing pressures and system flow rates are presented in Figure 11.

### 8.3 Commodity Damage Results:

The test arrangement was reviewed for fire test damage to the stored commodity.

In Test 9, the fire damage extended to a single pallet load beyond the 16 ft. spaced vertical barriers to the East. No target array ignition occurred, however there was partial melting of the exposed surface of the target array across the 8 ft. aisle space.

In Test 10, the fire damage was constrained within the vertical barriers except for incidental damage just outside the barrier to the West end of the array. No target array ignition occurred, however there was partial melting of the exposed surface of the target array across the 8 ft. aisle space.

Detailed photographs of the damage assessment are presented in Appendix C for Test 9 and in Appendix D for Test 10.

Drawings illustrating the damage to the commodity are depicted in Figure 23 and Figure 24 for Test 9, and in Figure 25 and Figure 26 for Test 10.
Figure 23  Test 9 Damage Assessment - Elevation View of North Main Array
Figure 24  Test 9 Damage Assessment - Elevation View of South Main Array
Figure 25  Test 10 Damage Assessment - Elevation View of North Main Array
Figure 26 Test 10 Damage Assessment - Elevation View of South Main Array
9. SUMMARY

9.1 General

Two large scale fire tests were conducted to develop data regarding the level of protection provided by ESFR sprinklers installed to protect a double-row rack arrangement of exposed, expanded Group A plastics stored up to 25 ft. high under a 30 ft. ceiling with vertical barriers installed within the rack array. No transverse flue space blocking was used in the test.

The ignition of the test commodity created a fire that grew very rapidly both vertically and horizontally.

In Test 9, the operation of the first sprinkler occurred at 47 seconds after ignition. A total of 7 sprinklers operated with the last sprinkler operating at 1 minute 24 seconds after ignition. The fire travelled beyond the vertical barrier east of the ignition location, but did not spread to the ends of the main test array. Neither target array was ignited during Test 9.

In Test 10, the operation of the first sprinkler occurred at 53 seconds after ignition. A total of 7 sprinklers operated with the last sprinkler operating at 1 minute 14 seconds after ignition. The fire was contained within the vertical barriers except for incidental damage just outside the barrier to the West end of the array. Neither target array ignited during Test 10.

There was no ignition of the target commodity in either test across the 8 ft. aisle, although partial melting of the commodity was witnessed due to the intensity of the radiation from the main rack array for both tests.

Where breaching of the vertical barriers occurred during the tests, it was observed that the fire travelled around the barrier at the aisle face where the commodity extended approximately 4 inches beyond the face of the uprights or vertical barriers. No through penetrations of the plywood barriers were seen.

Test parameters and results are summarized in Table 2.
## Table 2  Test Parameters and Results

<table>
<thead>
<tr>
<th>Fire Test Number</th>
<th>9</th>
<th>10</th>
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<tbody>
<tr>
<td>Test Date</td>
<td>October 28, 2014</td>
<td>October 30, 2014</td>
</tr>
<tr>
<td><strong>Test Parameters</strong></td>
<td></td>
<td></td>
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<tr>
<td>Storage Type</td>
<td>Double Row Rack</td>
<td></td>
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<tr>
<td>Commodity Type</td>
<td>Exposed Expanded Group A Plastic (Bagged Meat Trays on Hardwood Pallets)</td>
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<tr>
<td>Pallet Type</td>
<td>2 way entry, stringer, hardwood</td>
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<tr>
<td>Vertical Barriers</td>
<td>16 ft. on center - Main Array (3/8 in. plywood)</td>
<td>None</td>
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<tr>
<td>Length of Main Storage Array, ft.</td>
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<tr>
<td>Nominal Storage Height, ft.</td>
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<td>25</td>
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<tr>
<td>Ceiling Height, ft.</td>
<td>30</td>
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<tr>
<td>Nominal Clearance, ft.</td>
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<td>5</td>
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<tr>
<td>Aisle Width, ft.</td>
<td>8</td>
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<tr>
<td>Ignition Location</td>
<td>Under One Sprinkler (offset)</td>
<td>Between Two Sprinklers (offset)</td>
</tr>
<tr>
<td>Sprinkler Systems</td>
<td>Ceiling Only (no in-rack sprinklers)</td>
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<tr>
<td>Sprinkler Orientation</td>
<td>Pendent</td>
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<td>Deflector to Ceiling, in.</td>
<td>14</td>
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<td>Sprinkler Spacing, sprinkler by branchline ft. by ft.</td>
<td>10 by 10</td>
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</tr>
<tr>
<td>Temperature Rating, °F</td>
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<td>Sprinkler Type</td>
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<td>Nominal Sprinkler Discharge Coefficient K, gpm/psig 0.5</td>
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<td>Nominal Discharge Density, gpm/ft²</td>
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<td>Nominal Discharge Pressure, psig</td>
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<td><strong>Test Results</strong></td>
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<tr>
<td>Length of Test, minutes</td>
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<tr>
<td>First Sprinkler Operation Time, min:sec</td>
<td>0:47</td>
<td>0:53</td>
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<tr>
<td>Last Sprinkler Operation Time, min:sec</td>
<td>1:24</td>
<td>1:14</td>
</tr>
<tr>
<td>Number of Operated Sprinklers</td>
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<tr>
<td>Peak Gas Temperature at Ceiling Above Ignition, °F</td>
<td>204</td>
<td>990</td>
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<td>Maximum 1 minute Average Gas Temperature at Ceiling Above Ignition, °F</td>
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<td>Peak Steel Temperature at Ceiling Above Ignition, °F</td>
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<td>149</td>
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<tr>
<td>Maximum 1 minute Average Steel Temperature at Ceiling Above Ignition, °F</td>
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<td>144</td>
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<tr>
<td>Fire Travel to Extremities of Test Array</td>
<td>No</td>
<td>No</td>
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</table>
APPENDIX A

Temperature, Flow and Pressure Graphs

Test 9
Appendix A – Temperature, Flow and Pressure Graphs – Test 9

Figure A-1  Ceiling Sprinklers 1 through 8

Figure A-2  Ceiling Sprinklers 9 through 16
Appendix A – Temperature, Flow and Pressure Graphs – Test 9

Figure A-3  Ceiling Sprinklers 17 through 24

Figure A-4  Ceiling Sprinklers 25 through 32
Appendix A – Temperature, Flow and Pressure Graphs – Test 9

Figure A-5 Ceiling Sprinklers 33 through 40

Figure A-6 Ceiling Sprinklers 41 through 48
Figure A- 7  Ceiling Sprinklers 49 through 56

Figure A- 8  Ceiling Sprinklers 57 through 64
Figure A-9  Ceiling Steel Beam Temperature Above Ignition

Figure A-10  Ceiling Gas Temperature Above Ignition
Figure A-11  Ceiling Sprinkler System Flow rate and Pressure
APPENDIX B

Temperature, Flow and Pressure Graphs

Test 10
Figure B - 1  Ceiling Sprinklers 1 through 8

Figure B - 2  Ceiling Sprinklers 9 through 16
Figure B - 3  Ceiling Sprinklers 17 through 24

Figure B - 4  Ceiling Sprinklers 25 through 32
Figure B - 5 Ceiling Sprinklers 33 through 40

Figure B - 6 Ceiling Sprinklers 41 through 48
Figure B - 7  Ceiling Sprinklers 49 through 56

Figure B - 8  Ceiling Sprinklers 57 through 64
Figure B - 9  Ceiling Steel Beam Temperature Above Ignition

Figure B - 10  Ceiling Gas Temperature Above Ignition
Figure B - 11  Ceiling Sprinkler System Flow rate and Pressure
APPENDIX C

Damage Assessment Photographs

Test 9
Figure C - 1  Overall View - From Southeast
Figure C - 2  Overall View - From Northwest
Figure C - 3 Overall View - From West
Appendix C – Damage Assessment Photographs – Test 9

Figure C - 4   Overall View - From East
Figure C - 5  View of North Main Array
Figure C - 6   View of South Main Array
Figure C - 7  View of Combustible Barriers from the Northeast with Commodity Removed
Figure C - 8  View of Combustible Barriers from the Northwest with Commodity Removed
APPENDIX D

Damage Assessment Photographs

Test 10
Figure D - 1  Overall View - From Southeast
Figure D - 2  Overall View - From Northwest
Figure D - 3  Overall View - From West
Figure D - 4  Overall View - From East
Figure D - 5  View of North Main Array
Figure D - 6  View of South Main Array
Figure D - 7  View of Combustible Barriers from the Northeast with Commodity Removed
Figure D - 8  View of Combustible Barriers from the Northwest with Commodity Removed