TECHNICAL REPORT SUPPORTING CODE CHANGE

Summary Report of Fire Testing Involving Small Metal Containers in Palletized and Rack Storage – for NFPA 30

Summary Report of Fire Testing Involving Small Metal Containers in Palletized and Rack Storage

(Document prepared in support of code changes)

Extracted and edited by

Jill Norcott and John A. LeBlanc
Chief Engineer's Group
FM Global

For

NFPA 30 Flammable and Combustible Liquid Code

June 2022

Disclaimer

Table of Contents

List of Figures

List of Tables

1. **Introduction**

The term ignitable liquid as used in this report and by FM Global refers to any liquid that can burn. Ignitable liquids include all flammable and combustible liquids as defined by NFPA 30.

1.1 Background

The contents of this report are being submitted to support the following Public Comments made to NFPA 30-2021:

Table 1-1: Summary of Code Changes

Public Comment No.	NFPA 30 Section	Subject	Public Report Section(s) Supporting Changes
56	Table 16.5.2.2	Modification to protection criteria for palletized liquids in 6.5 gal (24.6 L) or smaller metal containers	3.1, 3.2
54	Table 16.5.2.1	Addition of face sprinklers for rack storage of liquids in uncartoned 5 gal (19 L) or smaller metal containers	3.3

This report was compiled from two (2) full scale fire test programs conducted by FM Global. The test work, which spans from 2008 through 2016, was aimed at defining adequate fire protection for the storage of ignitable liquids. This testing covered the following liquid types:

a. Low flash point hydrocarbon liquids in 5 gal (19 L) uncartoned metal containers.
b. High flash point hydrocarbon liquids in 5 gal (19 L) uncartoned metal containers.
c. Low flash point hydrocarbon liquids in 1 gal (3.8 L) cartoned metal containers.

The storage arrays were palletized and rack arrangements.

1.2 Organization of this Report

As noted above, this document contains documentation from two (2) full scale fire test programs. Each program is presented in Section 3.0. Each section is fully self-contained. Not all the tests that may have been carried out in a particular research program are included. Only tests that are related to the public comments are in this report. Resulting gaps in test numbering ensure the original content is maintained as written by the original author.

The content of this report correlates with the various Public Comments as shown in Table 1-1.

2. **FM Global Test Facilities Information**

The Fire Technology Laboratory is located at the FM Global Research Campus in West Glocester, Rhode Island, USA. Figure 2-1 is a plan view of the Large Burn Lab (LBL) showing the North movable ceiling, the South movable ceiling, and the 20-MW Calorimeter. The air emission control system (AECS) exhaust ducting for each movable ceiling consists of four extraction points, located at the lab ceiling, that merge into a single duct with a cross sectional area of 66 ft^2 (6.1 m^2). Gas concentration, velocity, temperature and moisture measurements are made downstream of the manifold. Beyond the measurement location, the exhaust duct connects to a wet electrostatic precipitator (WESP) prior to the gases venting to the atmosphere. The movable ceilings measure 80 ft x 80 ft (24.4 m x 24.4 m) and are adjustable for heights above the floor ranging from 10 ft to 60 ft (3.1 m to 18.3 m). All large-scale tests are conducted at an exhaust rate of 200,000 ft^3/min (94 m^3/s). The lab is provided with an advanced humidity control system to ensure testing consistency. The system circulates up to 104,000 ft^3/min (49 m^3/s) of air and removes up to one ton (900 kg) of water per hour.

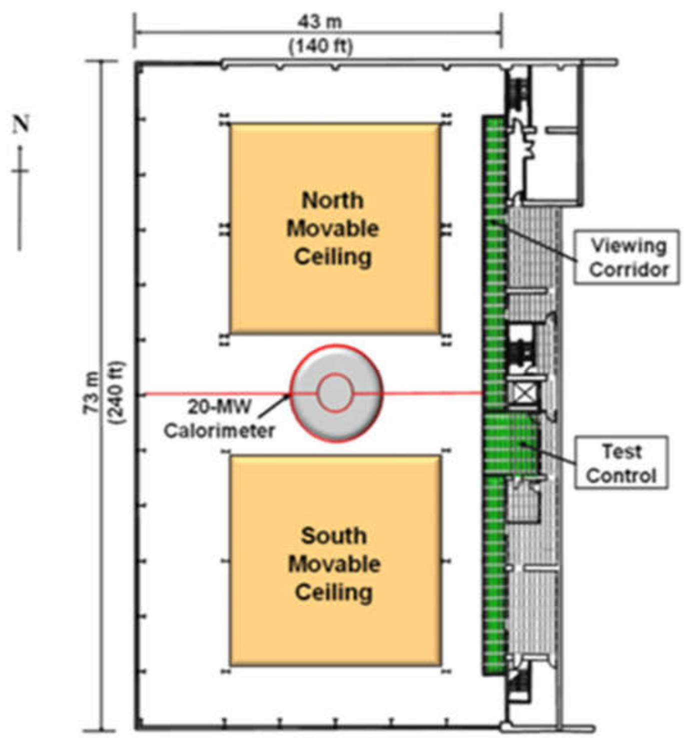


Figure 2-1: Illustration of FM Global Large Burn Laboratory test locations.

3. **Test Summaries**

3.1 Evaluation of Fire Protection for Five-Gallon Metal Containers / Jaap de Vries and Christopher J. Wieczorek / December 2010

3.1.1 Test Overview

The test facility used for this program is described in Section 2. A summary of the fire tests is provided in Table 3-1.

Table 3-1: Fire Test Summary

Test No.	1	2	3	4	5
Test Date	1/15/2008	1/17/2008	1/22/2008	1/24/2008	1/28/2008
PARAMETERS					
Commodity	Mineral Seal Oil Filled Metal Containers	Mineral Seal Oil Filled Metal Containers	Heptane Filled Metal Containers	Heptane Filled Metal Containers	Heptane Filled Metal Containers
Storage Arrangement	Palletized	Palletized	Palletized	Palletized	Palletized
Array Nominal Size - LxWxH (ft x ft x ft [*m x m x m*])	15 x 11.5 x 19 [*4.6 x 3.5 x 5.8*]	15 x 11.5 x 11.4 [*4.6 x 3.5 x 3.5*]	15 x 11.5 x 7.6 [*4.6 x 3.5 x 2.3*]	15 x 11.5 x 7.6 [*4.6 x 3.5 x 2.3*]	15 x 11.5 x 3.1 [*4.6 x 3.5 x 1.2*]
Stack Height (ft-in. [*m*])	19 [*5.8*]	11-5 [*3.5*]	7-7 [*2.3*]	7-7 [*2.3*]	3-10 [*1.2*]
No. of Storage Levels	5	3	2	2	1
Ceiling Height (ft [*m*])	30 [*9.1*]	30 [*9.1*]	30 [*9.1*]	30 [*9.1*]	30 [*9.1*]
Ignition Centered Below (*No. Ceiling Sprinklers*)	1	1	1	1	1
PROTECTION - CEILING					
Sprinkler K-factor (gpm/psi$^{1/2}$ [*lpm/bar$^{1/2}$*])	5.6 [*80.8*]	5.6 [*80.8*]	8.0 [*115*]	14 [*201*]	14 [*201*]
Sprinkler Temperature Rating (°F [°*C*]) / RTI	165 [*74*]/SR	165 [*74*]/SR	165 [*74*]/SR	165 [*74*]/QR	165 [*74*]/QR
Sprinkler Spacing (ft x ft [*m x m*])	10 x 10 [*3.0 x 3.0*]	10 x 10 [*3.0 x 3.0*]	10 x 10 [*3.0 x 3.0*]	10 x 10 [*3.0 x 3.0*]	10 x 10 [*3.0 x 3.0*]
Sprinkler Discharge Pressure (psig [*bar*])	29 [*2.0*]	13 [*0.9*]	56 [*3.7*]	18 [*1.2*]	18 [*1.2*]
Sprinkler Discharge Density (gpm/ft^2 [*mm/min*])	0.3 [*12.3*]	0.2 [*8.2*]	0.6 [*24.6*]	0.6 [*24.6*]	0.6 [*24.6*]
RESULTS					
First Sprinkler Operation (min:s)	8:33[a]	8:08	4:56	2:55	4:46
Last Sprinkler Operation (min:s)	8:33[a]	17:08	16:37	9:16	8:29
Total Sprinklers Opened	1[a]	29	25	27	7
Peak Gas Temperature (°F [°*C*])	268 [*131*]	723 [*384*]	1489 [*809*]	784 [*418*]	210 [*99*]
Peak Ceiling Steel Temperature (°F [°*C*])	94 [*34*]	193 [*91*]	390 [*199*]	195 [*91*]	109 [*43*]
Test Concluded (min:s)	8:23	17:00	7:30	9:20	20:00

[a] First sprinkler operated 10 seconds after terminating the test

3.1.2 Test Setup

3.1.2.1 <u>Commodity</u>

For Test 1 and Test 2, the commodity consisted of 5 gal (19 L) metal containers filled with mineral seal oil. For Test 3, Test 4 and Test 5, the commodity consisted of 5 gal (19 L) metal containers filled with heptane.

The metal containers were 5 gal (19 L) tight-head containers with plastic pour spouts. The cylindrical metal containers were 13.5 in. (34.3 cm) high with an outside diameter of 11 in. (27.9 cm). Each container was equipped with a relieving-style closure.

For all five tests, thirty-six metal containers were fitted on a 42 in. by 42 in. (1.07 m by 1.07 m) pallet in a horizontally staggered fashion. Each pallet load was 45.6 in. (1.16 m) high and wrapped in plastic sheathing. Pallet arrangements for mineral seal oil and heptane tests were identical. Figure 3-1 shows a typical pallet load.

Table 3-2 shows a summary of the properties for the fuels used in this study.

Table 3-2: Summary of properties of liquid fuels used in this study

Property	**Mineral Seal Oil**	**Heptane**
Class	IIB	IB
Closed Cup Flash Point (°F [*°C*])	264 [*129*]	25 [-*4*]
Open Cup Flash Point (°F [*°C*])	275 [*135*]	30.2 [-*1*]
Auto Ignition Temperature (°F [*°C*])	NA	399 [*204*]
Boiling Point (1 atm) (°F [*°C*])	480 – 680 [*249 – 360*]	209 [*98.4*]
Specific Gravity (Water = 1)	0.82	0.684
Solubility in Water	Immiscible	Immiscible
Heat of Combustion (BTU/lb [*MJ/kg*])	19,735 [*45.9*]	19,175 [*44.6*]
Heat of Vaporization (BTU/lb [k*J/kg*])	NA	137 [*318*]
Mass Burn Rate (lb/ft^2s [g/m^2s])	NA	0.021 [*101*]
Viscosity (@25°C) (cP)	4.17	0.386

3.1.2.2 <u>Storage Arrangement</u>

3.1.2.2.1 General

In all tests, the commodity arrangement had a similar footprint (2 pallets by 2 pallets) with targets located on the west, north and east sides of the main array. Targets consisted of metal cores taken from standard Class II commodities placed on wood pallets. They were positioned adjacent to the main array leaving 6 in. (15 cm) or 12 in. (31 cm) flue spaces. Figure 3-2 shows the plan view of the array for all five tests.

For each test, the ceiling was adjusted to a height of 30 ft (9.1 m).

3.1.2.2.2 Test 1 (mineral seal oil, five-tier high)

The five-tier high, palletized main array (twenty pallet loads) consisted of containers filled with mineral seal oil as described in Section 3.1.2.1. The clearance between the link of the upright sprinkler and the top of the commodity was 11.7 ft (3.57 m). Figure 3-3 shows the array setup for Test 1.

3.1.2.2.3 Test 2 (mineral seal oil, three-tiers high)

The three-tier high, palletized main array (twelve pallet loads) consisted of containers filled with mineral seal oil as described in Section 3.1.2.1. The clearance between the link of the upright sprinkler and the top of the commodity was 17.9 ft (5.46 m). Figure 3-4 shows the array setup for Test 2.

3.1.2.2.4 Test 3 and Test 4 (heptane, two-tiers high)

The two-tier high, palletized main array (eight pallet loads) consisted of containers filled with heptane as described in Section 3.1.2.1. The clearance between the link of the upright sprinkler and the top of the commodity was 23.1 ft (7.04 m). Figure 3-5 shows the array setup for Test 3 and Test 4.

3.1.2.2.5 Test 5 (heptane, one-tier high)

The one-tier high, palletized main array (four pallet loads) consisted of containers filled with heptane as described in Section 3.1.2.1. The clearance between the link of the upright sprinkler and the top of the commodity was 25.5 ft (7.77 m). Figure 3-6 shows the array setup for Test 5.

3.1.2.3 Ignition Method

Ignition was established by a 2 gal (7.6 L) spill of mineral seal oil (Tests 1 and 2) or heptane (Tests 3, 4 and 5). The small pool created by the spill was ignited via a propane torch. The ignition location is shown in Figure 3-2.

3.1.2.4 Instrumentation

Eighty-one (81) thermocouples were located near the ceiling to monitor the gas temperatures. The ceiling thermocouple configuration is shown in Figure 3-7. Additionally, nine (9) thermocouples were imbedded into two steel angles at the ceiling to monitor the steel temperature.

3.1.3 Protection

Ceiling-only protection was provided for all five tests. Forty-nine sprinklers were installed at a spacing of 10 ft by 10 ft (3.0 m by 3.0 m) for each test. Additional protection details are given in Table 3-3.

Table 3-3: Ceiling Protection

Test No.	K-factor (gpm/psi$^{1/2}$ [lpm/bar$^{1/2}$])	Temperature Rating (°F [°C])	Response / Orientation	Discharge Pressure (psig [bar])	Discharge Density (gpm/ft^2 [mm/min])
1	5.6 [80.8]	165 [74]	SR / Upright	29 [2.0]	0.3 [12.3]
2	5.6 [80.8]	165 [74]	SR / Upright	13 [0.9]	0.2 [8.20]
3	8.0 [115]	165 [74]	SR / Upright	56 [3.7]	0.6 [24.6]
4	14 [201]	165 [74]	QR / Upright	18 [1.2]	0.6 [24.6]
5	14 [201]	165 [74]	QR / Upright	18 [1.2]	0.6 [24.6]

3.1.4 Test Observations

3.1.4.1 Test 1 (mineral seal oil, five-tier high)

Right after ignition, the flame spread on the floor was approximately two pallets wide and initial flame height reached 5 – 6 ft (1.5 – 1.8 m). The initial fuel spill was consumed, and the pallets started to burn. At 0:36, the flames were reduced to the bottom tier. After one minute, smoke generation increased together with the average flame height. Flames up to 8 ft (2.5 m) were present in both the western and eastern flue spaces. A smoke layer of approximately 1 ft (0.3 m) was observed across the ceiling. The temperature at the ceiling remained below the 165°F (74°C) required to activate the sprinklers. The fire remained relatively stable during the following 2.5 minutes, generating light grey/opaque smoke. At 08:08, a major collapse occurred within the core array, falling towards the east. Right after collapse, the flames reached 20 ft (6.1 m) and the first and only sprinkler activated at 08:33. At 08:40, the test was terminated, and hose streams were applied.

3.1.4.2 Test 2 (mineral seal oil, three-tier high)

After ignition, fire propagation into the eastern and western flues occurred after one minute. At 01:22, it was observed that smoke generation was increasing and becoming slightly darker in color. Flames increased and reached 9 – 10 ft (2.5 – 2.8 m). Ceiling temperatures of 120°F (49°C) were reached six minutes into the test. The flames continued to increase in intensity reaching the top of the array and further increased to approximately 15 ft (4.5 m) at 07:30. First sprinkler activation was observed at 08:10. Stacks began to lean; the eastern stack came to rest against the western stack. No pool fire was observed at this point. At 13:35, the array collapsed causing an eruption of flames impinging on the ceiling and activating multiple sprinklers. Flames continued to reach approximately 25 ft (7.6 m) with no sign of fire control. A flammable liquid pool formed on the east side of the pan causing a vigorous fire. A total of 29 sprinklers operated. At 17:00, the test was terminated, and hose streams were applied.

3.1.4.3 Test 3 (heptane, two-tier high)

Right after ignition, flames remained 4 – 6 ft (1.2 – 1.8 m) high, predominantly located in the main longitudinal flue. At 1:00, flame heights increased to about 3 – 4 ft (0.9 – 1.2 m) above the top of the core array. Hissing and popping sounds were heard after 1.5 minutes. The initial spill spread, engulfing the core of the array in 1 – 2 ft (0.3 – 0.6 m) flames. Four minutes into the test, some cans were seen tipping over and liquid involvement was observed. At 4:10, part of the southeast stack collapsed into the longitudinal flue. A large jet flame developed rapidly while more liquid became involved in the fire. Flames were impinging on the ceiling and, at 4:56, the first sprinkler operated. In the next 2.5 minutes, 23 additional sprinklers opened with no sign of control. A large continuous jet flame originating from the core of the main array remained at ceiling level. At 7:30, the test was terminated, and foam hose streams were applied.

3.1.4.4 Test 4 (heptane, two-tier high)

Ignition condition and initial fire development were similar to those of Test 3. At 1:00, a popping noise was heard coming from the main array. In the next minute the flame height in the longitudinal flue was reduced with occasional flare ups to 10 ft (3 m). A rapid-fire flare was observed at 2:54, sending flames to the ceiling level and activating the first sprinkler. The first sprinkler discharge resulted in the flames being driven back to approximately 10 ft (3 m). At 3:10, heptane was seen pouring down to the floor in the main longitudinal flue which was totally engulfed in flames. At 4:40, flames were starting to increase and remained at 20 – 30 ft (6.1 – 9.1 m). At 5:50, a total of 13 sprinklers had opened with no visible sign of control. Flames were driven back slightly to approximately 20 ft (6.1 m). Flames were seen fluctuating in height between 15 ft (4.5 m) and ceiling level. After nine minutes, 21 sprinklers had operated while the fire intensity was increasing, reaching the ceiling and spreading out to a radius of 20 – 30 ft (6.1 – 9.1 m). At 9:20, the test was terminated, and foam hose streams were applied.

3.1.4.5 Test 5 (heptane, one-tier high)

After ignition, flames immediately reached approximately 3 – 4 ft (0.9 – 1.2 m) above the top of the main array. Within one minute a can was heard venting and a spout was seen flying off. At 2:45, some leaning was seen on the western stacks and, at 3:15, some collapse was witnessed into the longitudinal flue. Fire continued to intensify, and a flame height of 15 ft (5 m) was reached at 4:30 followed by the first sprinkler opening 15 seconds later. Some containers fell, creating a large pool fire causing four additional sprinklers to open. Sprinkler discharge significantly reduced the fire intensity over the next ten minutes. At 13:20, only very small flamelets were witnessed at floor level. The test was terminated at 20:00 with the fire completely suppressed.

3.1.5 Test Results

3.1.5.1 Test Evaluation Criteria

When dealing with ignitable liquids, the evaluation of fire test results involves the consideration of five key areas. They are:

- Number of Sprinklers Operated
  - This is a measure of what the needed water supply will be. Large sprinkler operating areas may not represent a viable sprinkler design.
- Sprinkler Operation Along the Edge of Ceiling Perimeter
  - All test facilities have limitations on producing a meaningful fire test. Beyond having a large enough volume to represent a large building volume, it is important to recognize that operation of any sprinkler in the last ring of sprinklers indicates that more sprinkler beyond could operate.
- Extent of Fire Damage
  - Fire testing arrays have limitations due to available fuel quantities. The fire spread must be contained within the fuel footprint in the array.
- Steel Temperatures
  - The ceiling temperatures created during a fire represent the level of thermal assault the building structural elements will see. Steel structures will lose strength if heated to temperatures above 1000°F (540°C). Target steel temperatures directly above a storage array must not exceed a one-minute average of 1000°F (540°C) or a recorded temperature of 1200°F (650°C).
- Pile Collapse

- This is unique to liquids storage arrays. A pile collapse can result in a large release of liquid and a significant increase in pool fire size.

3.1.5.2 Test 1 (mineral seal oil, five-tiers high)

Test 1 resulted in one (1) sprinkler activation. The test was terminated 8.5 minutes after ignition due to a major collapse. Figure 3-8 shows the ceiling sprinkler activation sequence, time, and location.

Gas and steel temperatures at the ceiling were also measured during the test. The maximum ceiling gas temperature during the test was 268°F (131°C) with a one-minute average temperature of 126°F (52°C). Figure 3-9 shows the ceiling gas temperature contour measurements five (5) seconds after the sprinkler activation. The maximum temperatures were recorded after collapse and test termination.

The maximum steel temperature was 94°F (34°C) with a one-minute average temperature of 93°F (34°C). Figure 3-10 shows the structural steel temperatures during Test 1. The maximum steel temperature remained below the limit of 1,200°F (650°C) prior to test termination.

The protection was considered unacceptable due to the collapse of the test array.

3.1.5.3 Test 2 (mineral seal oil, three-tiers high)

Test 2 resulted in twenty-nine (29) sprinkler activations. Figure 3-11 shows the ceiling sprinkler activation sequence, time, and location. Results showed no evidence of control during sprinkler operation and the test was terminated.

Gas and steel temperatures at the ceiling were also measured during the test. The maximum ceiling gas temperature was 723°F (384°C) with a one-minute average temperature of 327°F (164°C). Figure 3-12 shows the ceiling gas temperature contour at the time of the maximum ceiling temperature.

The maximum steel temperature was 193°F (91°C) with a one-minute average temperature of 191°F (88°C). Figure 3-13 shows the structural steel temperatures during Test 2. The maximum steel temperature remained below the limit of 1,200°F (650°C) prior to test termination.

The protection was considered unacceptable due to the collapse of the test array, activation of perimeter ceiling sprinklers, and the inability of the sprinklers to control the fire.

3.1.5.4 Test 3 (heptane, two-tiers high)

Test 3 resulted in twenty-five (25) sprinkler activations. Figure 3-14 shows the ceiling sprinkler activation sequence, time, and location. Results showed no evidence of control during sprinkler operation and the test was terminated.

Gas and steel temperatures at the ceiling were also measured during the test. The maximum ceiling gas temperature was 1,489°F (809°C) with a one-minute average temperature of 975°F (524°C). Figure 3-15 shows the ceiling gas temperature contour at the time of the maximum ceiling temperature.

The maximum steel temperature was 390°F (199°C) with a one-minute average temperature of 352°F (178°C). Figure 3-16 shows the structural steel temperatures during Test 3. The maximum steel temperature remained below the limit of 1,200°F (650°C) prior to test termination.

The protection was considered unacceptable due to activation of perimeter ceiling sprinklers, significant liquid spillage, and inability of the sprinklers to control the fire.

3.1.5.5 Test 4 (heptane, two-tiers high)

Test 4 resulted in twenty-seven (27) sprinkler activations. Figure 3-17 shows the ceiling sprinkler activation sequence, time, and location. Results showed no evidence of control during sprinkler operation and the test was terminated.

Gas and steel temperatures at the ceiling were also measured during the test. The maximum ceiling gas temperature was 784°F (418°C) with a one-minute average temperature of 257°F (125°C). Figure 3-18 shows the ceiling gas temperature contour at the time of the maximum ceiling temperature.

The maximum steel temperature was 195°F (91°C) with a one-minute average temperature of 173°F (78°C). Figure 3-19 shows the structural steel temperatures during Test 4. The maximum steel temperature remained below the limit of 1,200°F (650°C) prior to test termination.

The protection was considered unacceptable due to activation of perimeter ceiling sprinklers, significant liquid spillage, and inability of the sprinklers to control the fire.

3.1.5.6 Test 5 (heptane, one-tier high)

Test 5 resulted in seven (7) sprinkler activations. Figure 3-20 shows the ceiling sprinkler activation sequence, time, and location.

Gas and steel temperatures at the ceiling were also measured during the test. The maximum ceiling gas temperature was 210°F (99°C) with a one-minute average temperature of 152°F (67°C). Figure 3-21 shows the ceiling gas temperature contour at the time of the maximum ceiling temperature.

The maximum steel temperature was 109°F (43°C) with a one-minute average temperature of 108°F (43°C). Figure 3-22 shows the structural steel temperatures during Test 5. The maximum steel temperature remained below the limit of 1,200°F (650°C) prior to test termination.

The protection was considered acceptable. At the time of test termination, the fire was completely suppressed.

3.1.6 Conclusions

Full-scale testing conducted in this program demonstrated that ignitable liquids in palletized small metal containers represent a more challenging fire hazard than previously recognized. Palletized arrays limit the amount of cooling available at lower levels within the storage array resulting in container jetting and pile collapse. Even higher sprinkler densities failed to provide adequate cooling within the storage array. Although the 5-high palletized array of mineral seal oil only collapsed with minimal fire growth beyond the array, the 3-high palletized array demonstrated the potential for collapse followed by a significant increase in severity due to pool fire growth.

3.1.7 Figures

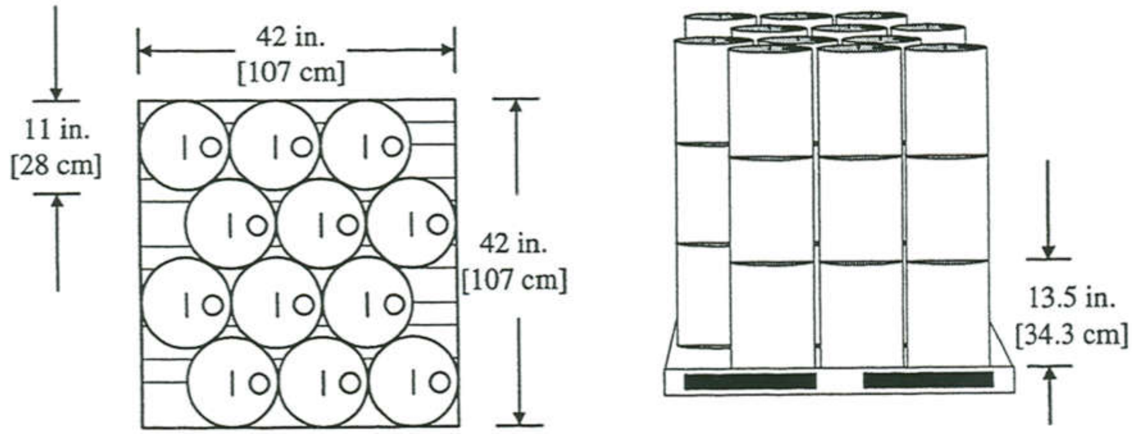


Figure 3-1: Pallet arrangement of 5 gal (19 L) metal containers.

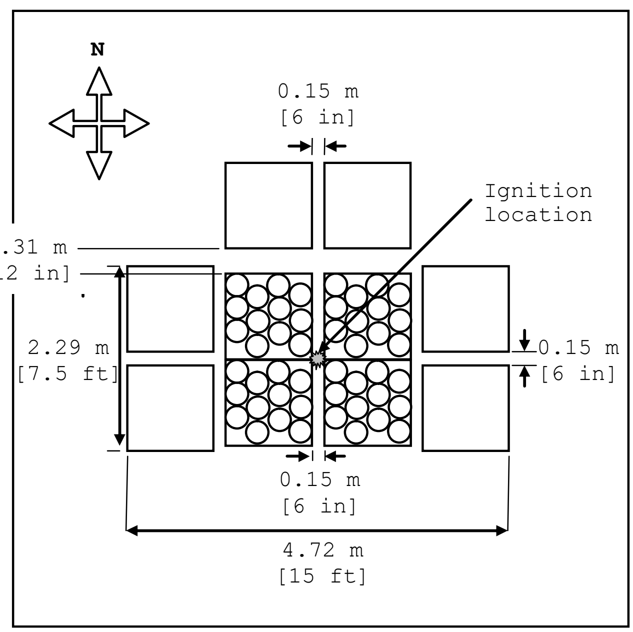


Figure 3-2: Plan view of test array.

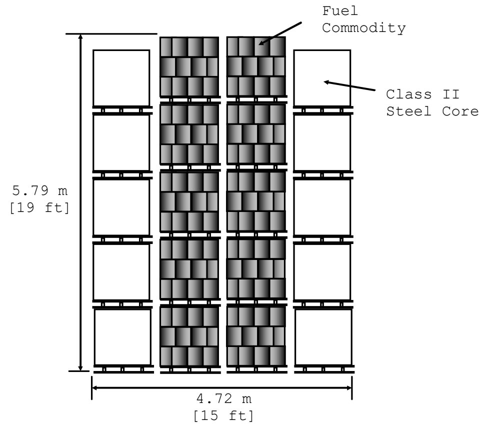


Figure 3-3: Array setup – Test 1.

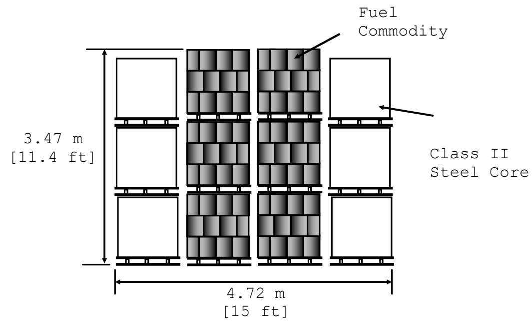


Figure 3-4: Array setup – Test 2.

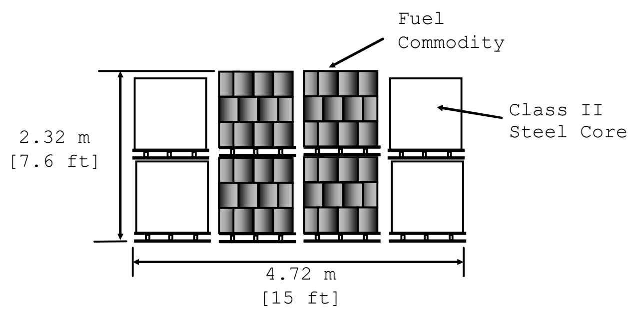


Figure 3-5: Array setup – Test 3 and Test 4.

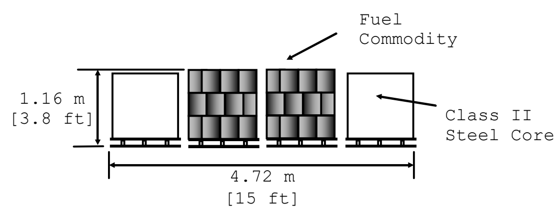


Figure 3-6: Array setup – Test 5.

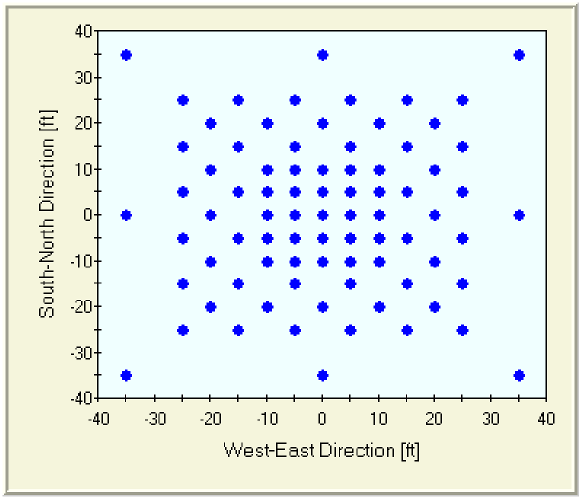
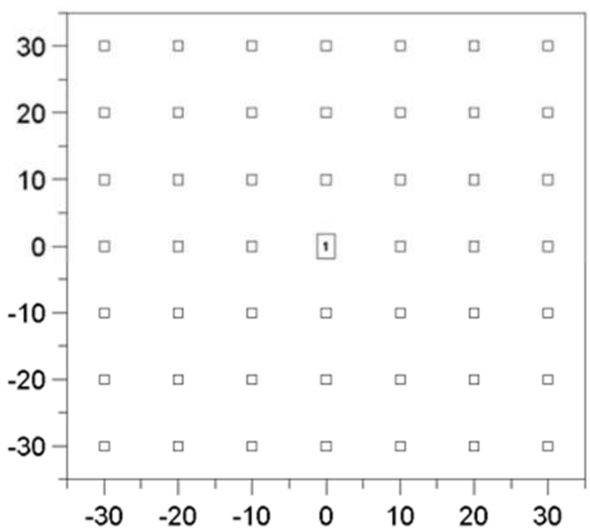


Figure 3-7: Thermocouple configuration.

3.1.8 Test Data



Operating Sequence	Time, min:sec	Spr #	Position, ft (X,Y,Z)
1	08:32.5	25	[0,0,-1.1]

Figure 3-8: Sprinkler operation for Test 1 – sequence, time and location.

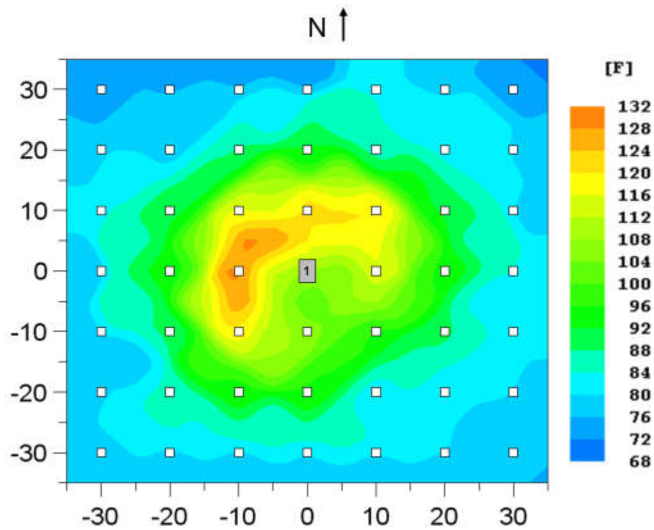


Figure 3-9: Ceiling gas temperature (5 sec after sprinkler operation) for Test 1.

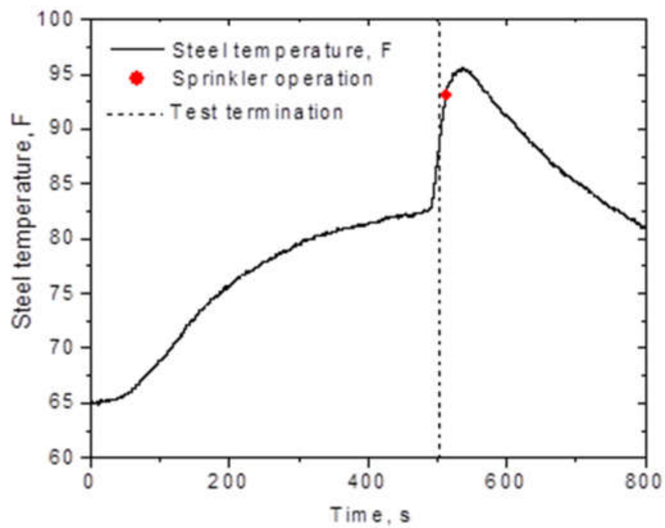
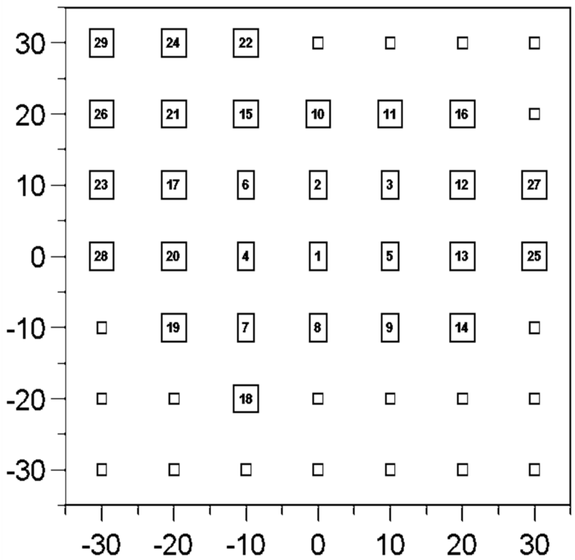


Figure 3-10: Steel temperature history for Test 1.



Operating Sequence	Time, min:sec	Spr #	Position, ft (X,Y,Z)
1	08:07.5	25	[0,0,-1.1]
2	13:40.5	18	[0,10,-1.1]
3	13:40.5	19	[10,10,-1.1]
4	13:40.5	24	[-10,0,-1.1]
5	13:40.5	26	[10,0,-1.1]
6	13:41.5	17	[-10,10,-1.1]
7	13:41.5	31	[-10,-10,-1.1]
8	13:41.5	32	[0,-10,-1.1]
9	13:41.5	33	[10,-10,-1.1]
10	13:44.5	11	[0,20,-1.1]
11	13:44.5	12	[10,20,-1.1]
12	13:44.5	20	[20,10,-1.1]
13	13:44.5	27	[20,0,-1.1]
14	13:44.5	34	[20,-10,-1.1]
15	13:45.5	10	[-10,20,-1.1]
16	13:46.5	13	[20,20,-1.1]
17	13:54.5	16	[-20,10,-1.1]
18	14:01.5	38	[-10,-20,-1.1]
19	14:15.5	30	[-20,-10,-1.1]
20	14:41.5	23	[-20,0,-1.1]
21	15:37.5	9	[-20,20,-1.1]
22	16:10.5	3	[-10,30,-1.1]
23	16:25.5	15	[-30,10,-1.1]
24	16:26.5	2	[-20,30,-1.1]
25	16:40.5	28	[30,0,-1.1]
26	16:43.5	8	[-30,20,-1.1]
27	17:05.4	21	[30,10,-1.1]
28	17:05.4	22	[-30,0,-1.1]
29	17:08.4	1	[-30,30,-1.1]

Figure 3-11: Sprinkler operation for Test 2 – sequence, time and location.

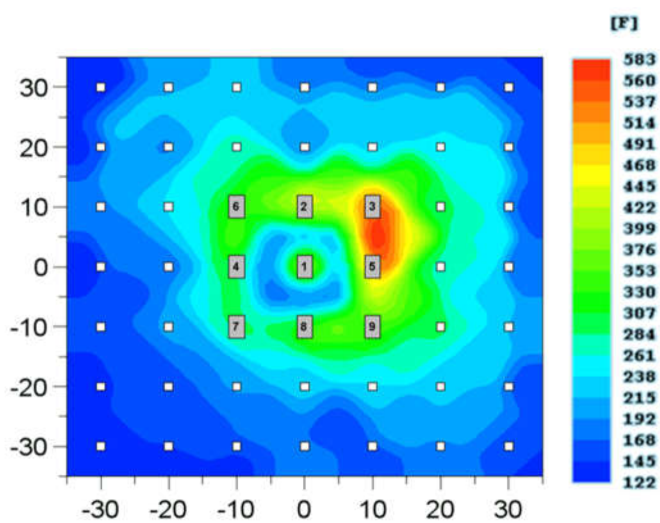


Figure 3-12: Ceiling gas temperatures for Test 2 at the time of maximum local value.

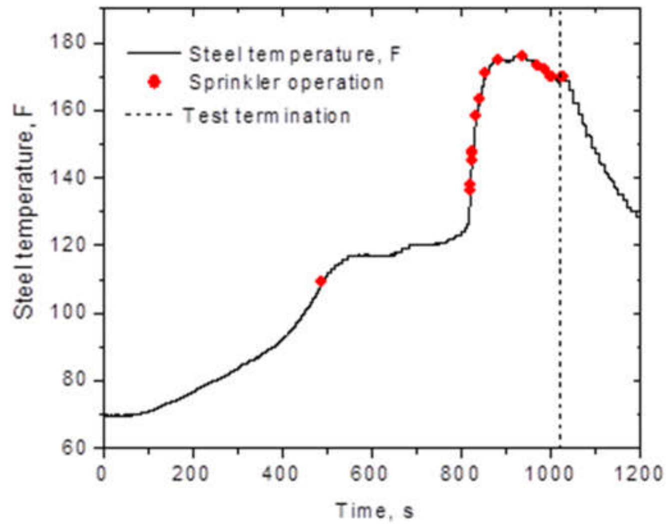
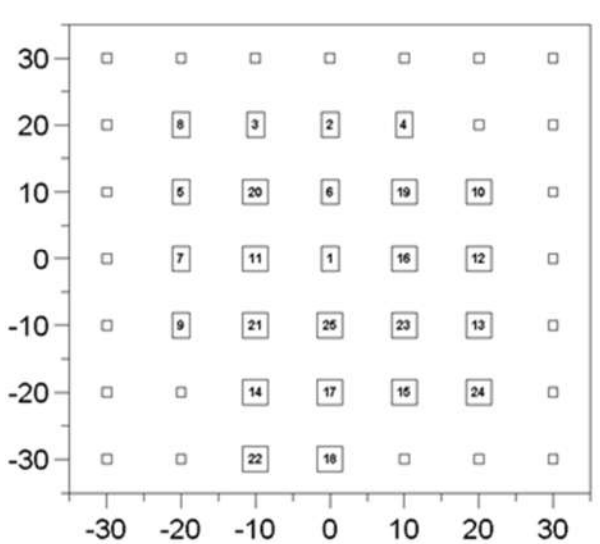


Figure 3-13: Steel temperature history for Test 2.



Operating Sequence	Time, min:sec	Spr #	Position, ft (X,Y,Z)
1	04:55.5	25	[0,0,-1.1]
2	05:58.5	11	[0,20,-1.1]
3	06:01.5	10	[-10,20,-1.1]
4	06:02.5	12	[10,20,-1.1]
5	06:02.5	16	[-20,10,-1.1]
6	06:02.5	18	[0,10,-1.1]
7	06:02.5	23	[-20,0,-1.1]
8	06:04.5	9	[-20,20,-1.1]
9	06:08.5	30	[-20,-10,-1.1]
10	06:09.5	20	[20,10,-1.1]
11	06:11.5	24	[-10,0,-1.1]
12	06:33.5	27	[20,0,-1.1]
13	06:34.5	34	[20,-10,-1.1]
14	06:37.5	38	[-10,-20,-1.1]
15	06:39.5	40	[10,-20,-1.1]
16	06:44.5	26	[10,0,-1.1]
17	06:51.5	39	[0,-20,-1.1]
18	06:51.5	46	[0,-30,-1.1]
19	06:52.5	19	[10,10,-1.1]
20	06:55.5	17	[-10,10,-1.1]
21	07:03.5	31	[-10,-10,-1.1]
22	07:03.5	45	[-10,-30,-1.1]
23	07:07.5	33	[10,-10,-1.1]
24	07:37.5	41	[20,-20,-1.1]
25	16:38.5	32	[0,-10,-1.1]

Figure 3-14: Sprinkler operation for Test 3 – sequence, time and location.

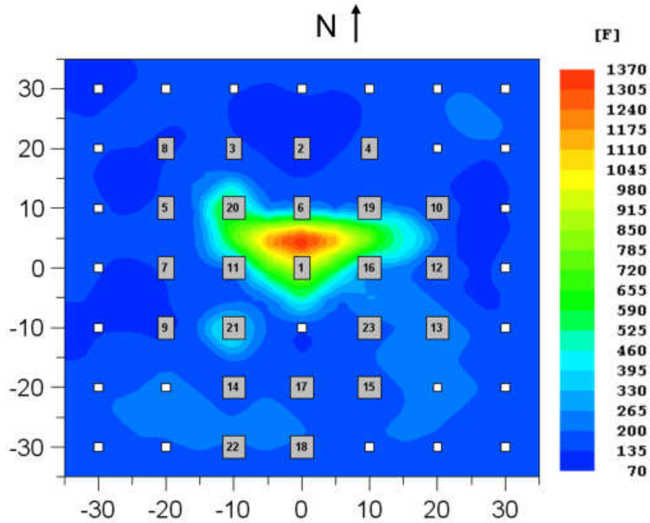


Figure 3-15: Ceiling gas temperatures for Test 3 at the time of maximum local value.

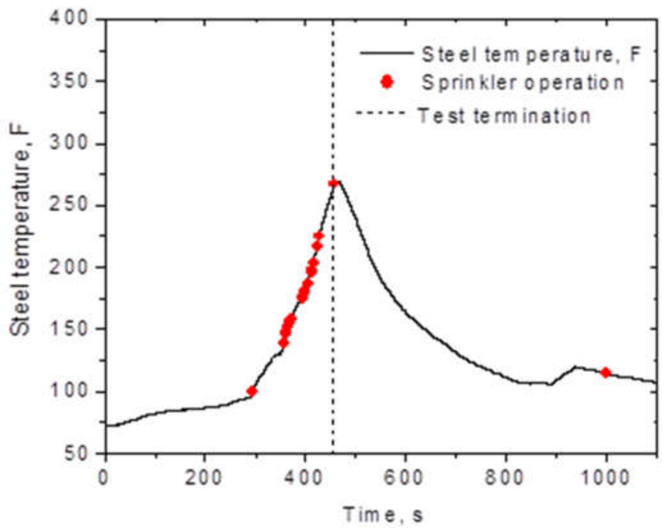
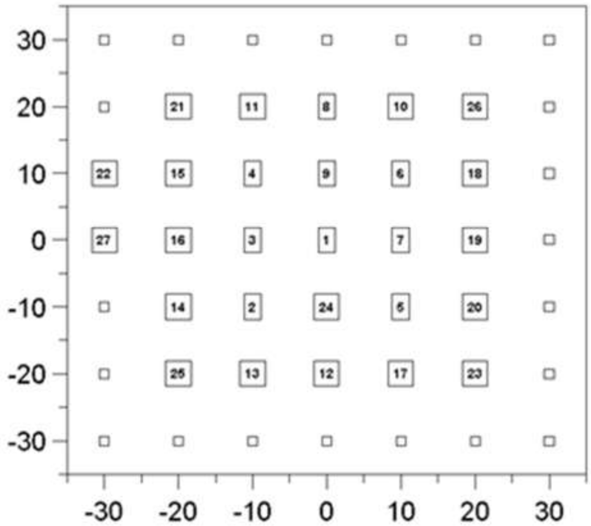


Figure 3-16: Steel temperature history for Test 3.



Operating Sequence	Time, min:sec	Spr #	Position, ft (X,Y,Z)
1	02:54.5	25	[0,0,-1.1
2	05:11.5	31	[-10,-10,-1.1
3	05:13.5	24	[-10,0,-1.1
4	05:17.5	17	[-10,10,-1.1
5	05:21.5	33	[10,-10,-1.1
6	05:27.5	19	[10,10,-1.1
7	05:27.5	26	[10,0,-1.1
8	05:31.5	11	[0,20,-1.1
9	05:31.5	18	[0,10,-1.1
10	05:32.5	12	[10,20,-1.1
11	05:37.5	10	[-10,20,-1.1
12	05:41.5	39	[0,-20,-1.1
13	05:43.5	38	[-10,-20,-1.1
14	05:44.5	30	[-20,-10,-1.1
15	05:45.5	16	[-20,10,-1.1
16	05:46.5	23	[-20,0,-1.1
17	05:54.5	40	[10,-20,-1.1
18	08:47.5	20	[20,10,-1.1
19	08:51.5	27	[20,0,-1.1
20	08:57.5	34	[20,-10,-1.1
21	09:01.5	9	[-20,20,-1.1
22	09:08.5	15	[-30,10,-1.1
23	09:08.5	41	[20,-20,-1.1
24	09:12.5	32	[0,-10,-1.1
25	09:13.5	37	[-20,-20,-1.1
26	09:15.5	13	[20,20,-1.1
27	09:15.5	22	[-30,0,-1.1

Figure 3-17: Sprinkler operation for Test 4 – sequence, time and location.

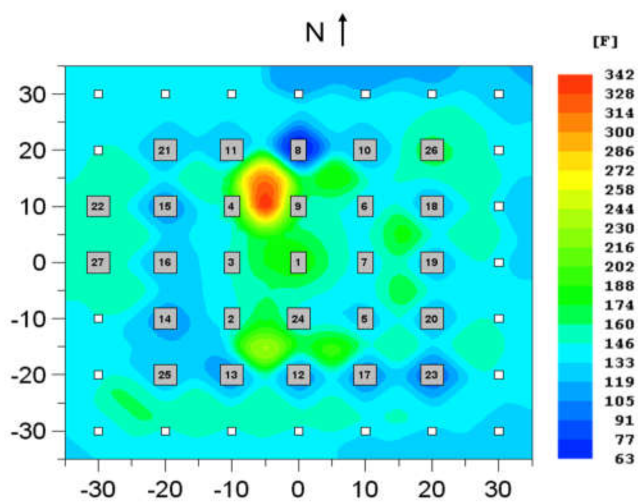


Figure 3-18: Ceiling gas temperatures for Test 4 at the time of maximum local value.

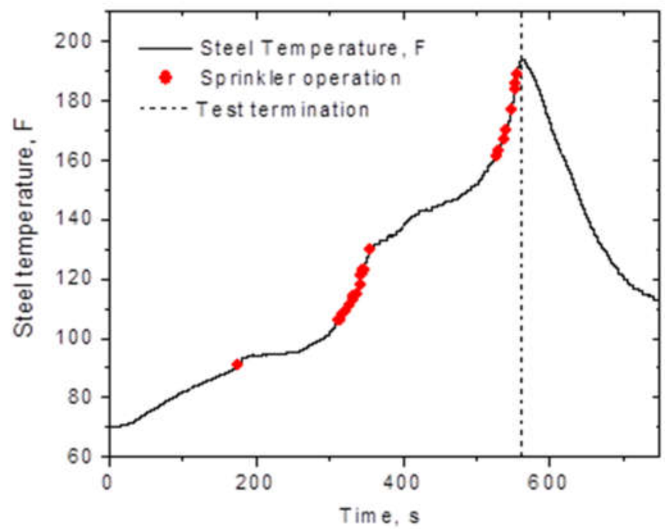
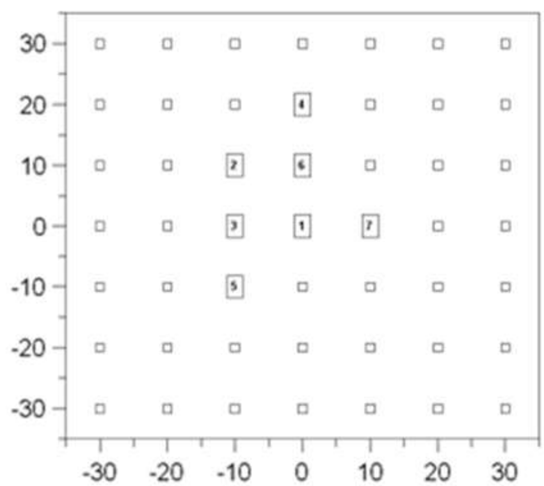


Figure 3-19: Steel temperature history for Test 4.



Operating Sequence	Time, min:sec	Spr#	Position, ft (X,Y,Z)
1	04:45.5	25	[0,0,-1.1]
2	05:13.5	17	[-10,10,-1.1]
3	05:13.5	24	[-10,0,-1.1]
4	05:16.5	11	[0,20,-1.1]
5	05:16.5	31	[-10,-10,-1.1]
6	07:09.5	18	[0,10,-1.1]
7	08:28.5	26	[10,0,-1.1]

Figure 3-20: Sprinkler operation for Test 5 – sequence, time and location.

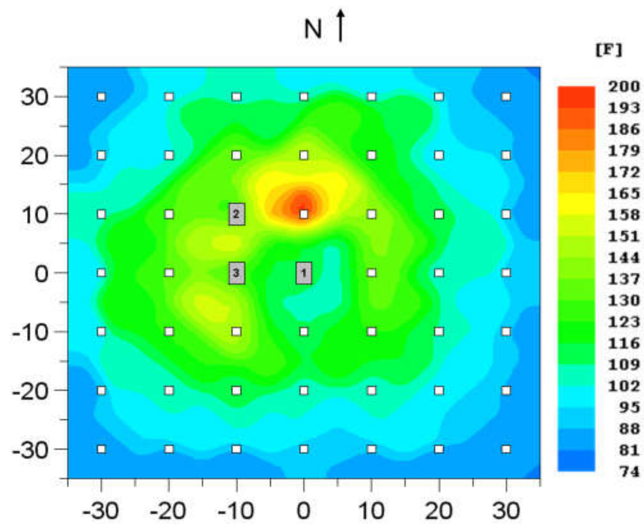


Figure 3-21: Ceiling gas temperatures for Test 5 at the time of maximum local value.

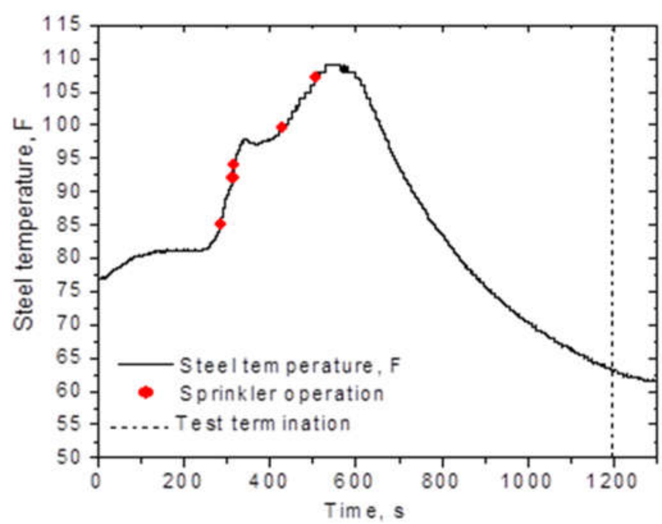


Figure 3-22: Steel temperature history for Test 5.

3.2 Protection for Ignitable Liquids in Small Metal Containers / Jaap de Vries / September 2018 (Palletized Storage Test)

3.2.1 Test Overview

The test facility used for this program is described in Section 2. Table 3-4 provides a summary of the fire test.

Table 3-4: Fire Test Summary

Test No.	2
Test Date	01/25/2016
PARAMETERS	
Commodity	Heptane Filled 1 gal Cartoned Metal Containers
Storage Arrangement	Palletized
Array Nominal Size – LxWxH (ft x ft x ft [*m x m x m*])	8.2 x 8.2 x 13 [2.5 *x 2.5 x 3.9*]
Stack Height (ft-in. [*m*])	14 [*4.3*]
No. of Storage Levels	3
Ceiling Height (ft [*m*])	30 [*9.1*]
Ignition Centered Below (*No. Ceiling Sprinklers*)	1
PROTECTION - CEILING	
Sprinkler K-factor (gpm/psi$^{1/2}$ [*lpm/bar$^{1/2}$*])	25.2EC [*360EC*]
Sprinkler Temperature Rating (^{o}F [^{o}*C*]) / RTI	165 [*74*]/QR
Sprinkler Spacing (ft x ft [*m x m*])	14 x 14 [*4.3 x 4.3*]
Sprinkler Discharge Pressure (psig [*bar*])	22 [*1.5*]
Sprinkler Discharge Density (gpm/ft^2 [*mm/min*])	0.6 [*24*]
RESULTS	
First Sprinkler Operation (min:s)	0:25
Last Sprinkler Operation (min:s)	24:58
Total Sprinklers Opened	7
Peak Gas Temperature (^{o}F [^{o}*C*])	572 [*300*]
Peak Ceiling Steel Temperature (^{o}F [^{o}*C*])	161 [*72*]
Test Concluded (min:s)	25:00

3.2.2 Test Setup

3.2.2.1 Commodity

The commodity consisted of 1 gal (3.8 L) metal containers filled with heptane placed in corrugated paperboard boxes.

The 1 gal (3.8 L), F-style containers were formed from 0.20 in. (0.51 cm) tinplate and fitted with a 1.25 in. (3.2 cm) relieving-style plastic nozzle and plastic cap. The container dimensions were 6.6 x 4.1 x 9.4

in. (17 x 11 x 24 cm). They were packed four per box inside single-wall corrugated paper cartons. The outer dimensions of the carton boxes were 14 x 8.7 x 11 in. (35 x 22 x 28 cm).

Cardboard boxes containing four (4) metal containers each were placed in four (4) layers on each hardwood pallet. Each layer contained 13 boxes. The 52 boxes in the pallet resulted in a per pallet liquid loading of 208 gal (787 L). Each pallet was wrapped in clear plastic stretch wrap. Figure 3-23 shows a typical pallet load.

The properties of the heptane have been provided in Table 3-2.

3.2.2.2 Storage Arrangement

The two by two by three-tier high, palletized main array (twelve pallet loads) consisted of containers filled with heptane as described in Section 3.2.2.1. The array, excluding targets, was 99 in. (2.5 m) wide by 99 in. (2.5 m) deep by 154 in. (3.9 m) high. There was a 6 in. (15 cm) flue between pallets. The clearance between the ceiling and the top of the commodity was 17 ft (5.2 m).

Targets consisted of three-tier high, palletized, metal container liners. Targets were located on three sides of the main array and positioned adjacent to the main array leaving 12 in. (31 cm) flue spaces.

Figure 3-24 shows the array setup for Test 2.

3.2.2.3 Ignition Method

Ignition was achieved with four half igniters. A half igniter is a 3 in. (7.6 cm) long 3 in. (7.6 cm) diameter cylinder of rolled cellucotton, soaked in 4 oz (118 mL) of gasoline and sealed in a plastic bag. The ignition location was at the bottom of the test array. The igniters were lit with a propane torch at the start of the test.

3.2.3 Protection

Ceiling-only protection was provided. Sprinklers were installed at a spacing of 14 ft by 14 ft (4.3 m by 4.3 m). Additional protection details are given in Table 3-6. Figure 3-25 shows the ceiling sprinkler locations with respect to the palletized storage arrangement. The extended coverage sprinklers use quick response links but behave as standard response sprinklers at the extended spacing.

Table 3-5: Ceiling Protection

Test No.	Sprinkler K-factor (gpm/psi$^{1/2}$ [lpm/bar$^{1/2}$])	Sprinkler Temperature Rating (°F [°C])	Response / Orientation	Sprinkler Discharge Pressure (psig [bar])	Sprinkler Discharge Density (gpm/ft^2 [mm/min])
2	25.2EC [360EC]	165 [74]	QR / Upright	22 [1.5]	0.6 [24]

3.2.4 Test Observations

Test 2 was initiated by four (4) half igniters at the center of the array, followed by rapid vertical fire growth. Twenty-five (0:25) seconds after ignition, the first sprinkler directly above the fire operated. Water from the sprinkler reduced the fire size to within the array briefly. At 1:10, the first containers started to rupture, and a large jet flame developed above the array. This flame continued unabated, and four more sprinklers activated by 3:26. The additional sprinklers did not suppress the jet fire. At 16:48, a sixth sprinkler activated. The final sprinkler activated at 24:58. At 25:00, the test was terminated. Hose streams with aqueous film forming foam (AFFF) were applied.

3.2.5 Test Results

The test evaluation criteria listed in Section 3.1.5.1 were applied to this test. Test 2 resulted in seven (7) sprinkler activations. The ceiling sprinkler activation sequence is shown in Figure 3-26. Both the ceiling gas and the structural steel temperatures remained relatively low throughout the test and were relatively flat at the time of test termination. Figure 3-27 shows the ceiling gas temperatures and Figure 3-28 shows the structural steel temperatures. The array did not collapse.

3.2.6 Conclusions

The provided protection controlled the fire of the palletized array.

3.2.7 Figures

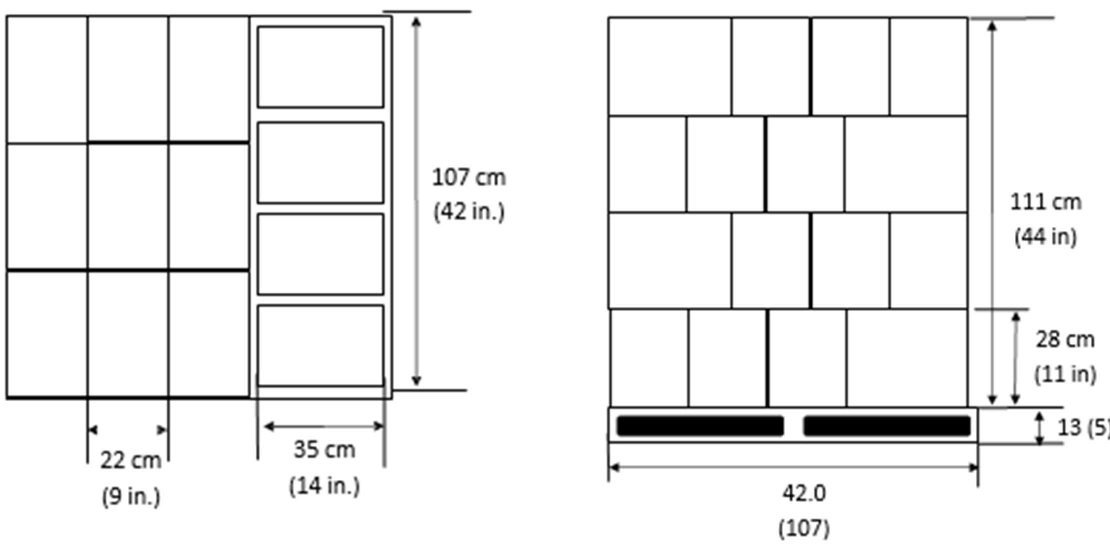


Figure 3-23: Plan view (left) and elevation view (right) showing example of cartoned 1 gal (3.8 L) metal containers stored four (4) per box.

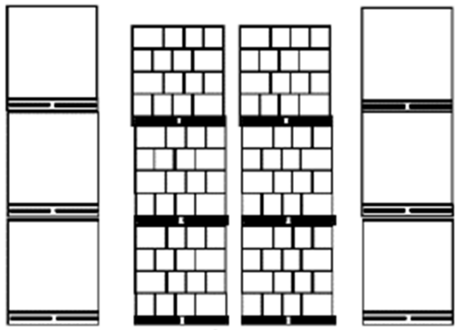
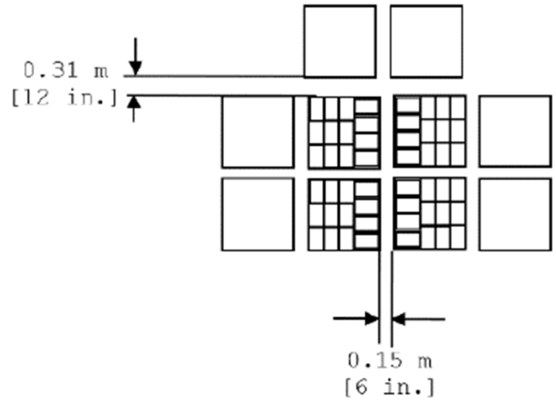



Figure 3-24: Palletized storage configuration for Test 2.

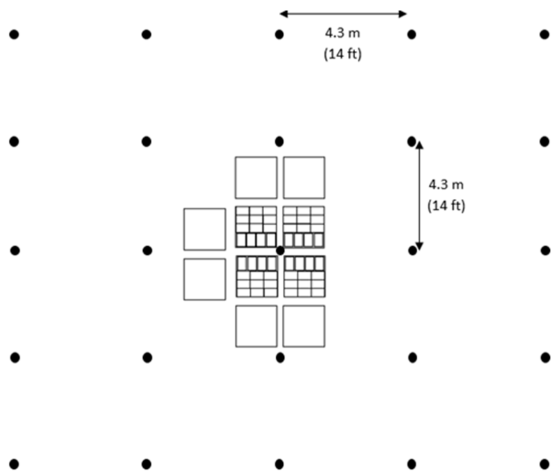
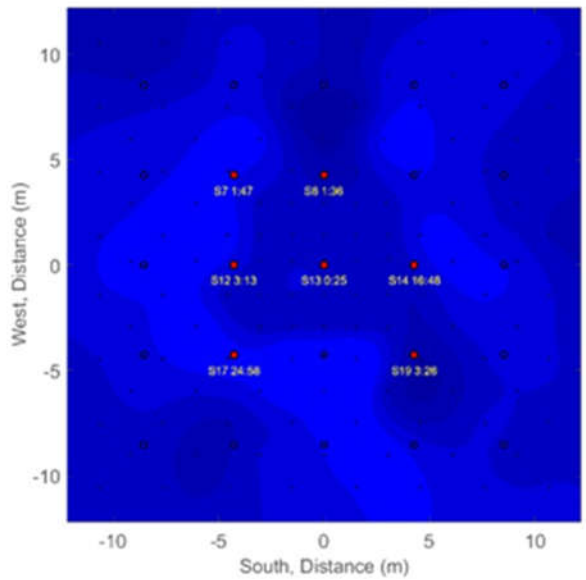


Figure 3-25: Plan view of ceiling sprinkler locations with respect to palletized storage arrangement.

3.2.8 Test Data



Sequence #	Sprinkler ID	Activation Time, mm:ss
Ceiling		
1	HEAD13	00:25.0
2	HEAD08	01:36.7
3	HEAD07	01:47.4
4	HEAD12	03:13.7
5	HEAD19	03:26.2
6	HEAD14	16:48.6
7	HEAD17	24:58.4

Figure 3-26: Sprinkler operation for Test 2 – sequence, time and location.

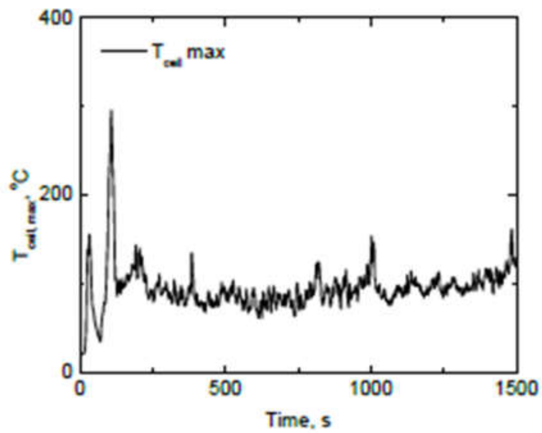


Figure 3-27: Ceiling temperature history for Test 2.

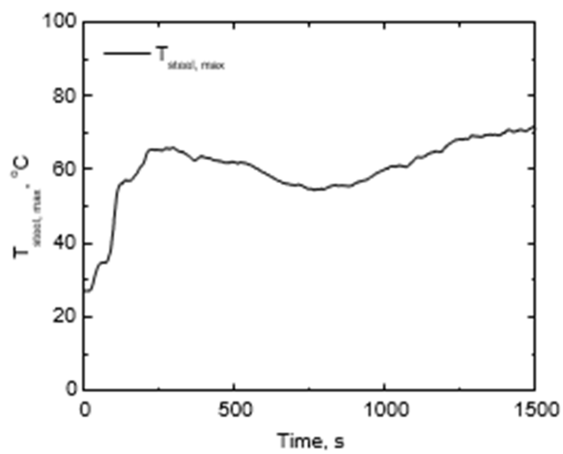


Figure 3-28: Steel temperature history for Test 2.

3.3 Protection for Ignitable Liquids in Small Metal Containers / Jaap de Vries / September 2018 (Rack Storage Tests)

3.3.1 Test Overview

The test facility used for this program has been described in Section 2. A summary of the fire testing is provided in Table 3-7.

Table 3-6: Fire Test Summary

Test No.	1	3
Test Date	01/15/2016	03/09/2016
PARAMETERS		
Commodity	Heptane Filled 5 gal Uncartoned Metal Containers	Heptane Filled 5 gal Uncartoned Metal Containers
Storage Arrangement	2 x 8 x 5 (Rack)	2 x 8 x 5 (Rack)
Array Nominal Size - LxWxH (ft x ft x ft [*m x m x m*])	*7.5 x 32 x 25* [*2.6 x 9.6 x 7.6*]	*7.5 x 32 x 25* [*2.6 x 9.6 x 7.6*]
Vertical Tier Separation (ft [*m*])	5 [*1.5*]	5 [*1.5*]
No. of Storage Levels	5	5
Ceiling Height (ft [*m*])	30 [*9.1*]	30 [*9.1*]
Ignition Centered Below (*No. Ceiling Sprinklers*)	4	4
PROTECTION - CEILING		
Sprinkler K-factor (gpm/psi$^{1/2}$ [*lpm/bar*$^{1/2}$])	8.0 [*115*]	11.2 [*160*]
Sprinkler Temperature Rating (^{o}F [^{o}*C*]) / RTI	286 [*141*] / SR	155 [*68*] / SR
Sprinkler Orientation	Pendent	Pendent
Sprinkler Spacing (ft x ft [*m x m*])	10 x 10 [*3.0 x 3.0*]	10 x 10 [*3.0 x 3.0*]
Sprinkler Discharge Pressure (psig [*bar*])	14 [*1.0*]	7 [*0.5*]
Sprinkler Discharge Density (gpm/ft^2 [*mm/min*])	0.3 [*12.3*]	0.3 [*12.3*]
PROTECTION – IRAS		
IRAS Layout	Longitudinal flue only	Longitudinal flue + face
Sprinkler K-factor (gpm/psi$^{1/2}$ [*lpm/bar*$^{1/2}$])	5.6 [*80*]	8.0 [115]
Sprinkler Temperature Rating (^{o}F [^{o}*C*]) / RTI	155 [68] / SR	155 [68] / QR
Vertical Spacing (tiers)	1 (staggered)	1 (staggered)
Horizontal Spacing (ft [*m*])	8 [*2.5*]	Face: 4 [*1.2*] Flue: 8 [*2.5*]
Sprinkler Discharge Pressure (psig [*bar*])	65 [*4.4*]	32 [2.2]
Sprinkler Design Flow (gpm [*l/min*])	45 [*170*]	45 [*170*]
RESULTS		
First Ceiling Sprinkler Operation (min:s)	3:11	N/A
Last Ceiling Sprinkler Operation (min:s)	4:59	N/A
Total Ceiling Sprinklers Opened	29[b]	0
First IRAS Sprinkler Operation (min:s)	2:40	0:18
Last IRAS Sprinkler Operation (min:s)	4:13	1:38
Total IRAS Sprinklers Opened	8	4
Peak Gas Temperature (^{o}F [^{o}*C*])	1734 [*945*]	195 [*91*]
Peak Ceiling Steel Temperature (^{o}F [^{o}*C*])	535 [*279*]	92 [*33*]
Test Concluded (min:s)	4:43	10:00

[b] An additional 11 sprinklers operated after test termination.

3.3.2 Test Setup

3.3.2.1 Commodity

The commodity for both tests consisted of uncartoned 5 gal (19 L) metal containers filled with heptane. The properties of heptane used in this study can be found in Table 3-2.

The 5 gal (19 L), tight-head metal containers used in this study weighed 4.5 lbs (2.1 kg) each. These cylindrical metal containers were 13.5 in. (34 cm) high and had a 11 in. (27.9 cm) outside diameter. Each container was equipped with a relieving-style closure.

Three layers of 5 gal (19 L) metal containers were placed on each 42 by 42 in. (1.1 by 1.1 m) hardwood pallet. Each layer contained 12 containers, resulting in 36 containers per pallet and a total liquid loading of 180 gal (681 L). Each pallet was wrapped in clear plastic stretch wrap. Figure 3-29 shows a typical pallet load.

3.3.2.2 Storage Arrangement

3.3.2.2.1 Test 1

The 2 x 8 x 5-tier high double-row rack storage array consisted of 32 pallet loads of containers filled with heptane as described in Section 3.3.2.1 and 48 pallet loads of Class 2 commodity. Class 2 commodity was used to keep the overall amount of ignitable liquid manageable and to provide combustible loading surrounding the ignitable liquids pallets to test for fire spread.

Targets, comprised of inert panels, were installed on the east and west sides of the rack storage array. Each target assembly was 25 ft wide by 26 ft high (7.6 m by 7.9 m) and was placed 8 ft (2.4 m) from the main array.

The ceiling was adjusted to a height of 30 ft (9.1 m). The clearance between the ceiling and the top of the commodity was 5 ft (1.5 m). Figure 3-30 shows the array setup for Test 1.

3.3.2.2.2 Test 3

The storage arrangement for Test 3 was nearly identical to that of Test 1, however, twenty-eight (28) of the Class 2 commodities were replaced with metal liners to prevent Class 2 corrugated cardboard from contributing to fire spread. The metal liners directly adjacent to the liquid-loaded pallets are also more representative of the metal containers themselves. Twenty (20) pallets of Class 2 commodity were used at the north and south ends of the main array.

Targets were identical to those used in Test 1.

Figure 3-31 shows the test array setup for Test 3.

3.3.2.3 Ignition Method

Ignition for both tests consisted of a 2 gal (7.6 L) heptane spill confined in a 94 in. long by 24 in. wide by 0.75 in. deep (239 cm by 61 cm by 2 cm) pan centered at the east face of the main array. The pan extended 6 in. (15 cm) out from the face of the array. The ignition pan was centered under four ceiling sprinklers.

3.3.2.4 Instrumentation

Four heat flux gauges were installed on the east target to provide data on the heat flux towards the target. A heat flux gauge was installed and centered in each of the bottom 4 tiers, facing the main array, starting at 3 ft (0.9 m) from the floor and spaced in 62 in. (1.6 m) vertical intervals. A schematic of the target array illustrating the heat flux gauge locations is shown in Figure 3-32.

3.3.3 Protection

3.3.3.1 Test 1 – Ceiling and IRAS (no face sprinklers)

Ceiling protection was provided using sixty-four (64) sprinklers installed at a spacing of 10 ft by 10 ft (3.0 m by 3.0 m). Additional ceiling protection details are given in Table 3-8. Figure 3-33 shows the ceiling sprinkler locations with respect to the rack storage arrangement for Test 1.

In-rack sprinklers were centered in every other intersection of the longitudinal and transverse flue, staggered above each tier on a 99 in. (2.5 m) spacing. The IRAS deflectors were placed 6 in. (15 cm) from the top of each pallet load. Additional IRAS protection details are given in Table 3-9. Figure 3-30 shows the in-rack sprinkler locations with respect to the rack storage arrangement in Test 1.

Table 3-7: Ceiling Protection

Test No.	K-factor (gpm/psi$^{1/2}$ [lpm/bar$^{1/2}$])	Temperature Rating (°F [°C])	Response / Orientation	Discharge Pressure (psig [bar])	Discharge Density (gpm/ft^2 [mm/min])
1	8 [*115*]	286 [*141*]	SR / Pendent	14 [*1.0*]	0.3 [*12*]
3	11.2 [*160*]	155 [*68*]	SR / Pendent	7 [*0.5*]	0.3 [*12*]

Table 3-8: In-Rack Protection

Test No.	K-factor (gpm/psi$^{1/2}$ [lpm/bar$^{1/2}$])	Temperature Rating (°F [°C])	Response / Orientation	Discharge Pressure (psig [bar])	Design Flow (gpm [L/min])
1	5.6 [*80*]	155 [*68*]	SR / Pendent	65 [*4.4*]	45 [*170*]
3	8 [*115*]	155 [*68*]	QR / Pendent	32 [*2.2*]	45 [*170*]

3.3.3.2 Test 3 – Ceiling and IRAS (with face sprinklers)

Ceiling protection was provided using sixty-four (64) sprinklers installed at a spacing of 10 ft by 10 ft (3.0 m by 3.0 m). Additional ceiling protection details are given in Table 3-8. Figure 3-34 shows the ceiling sprinkler locations with respect to the rack storage arrangement for Test 3.

In-rack sprinklers were centered in every other intersection of the longitudinal and transverse flue, staggered above each tier on a 99 in. (2.5 m) spacing. The IRAS deflectors were placed 6 in. (15 cm) from the top of each pallet load.

In addition, face sprinklers were installed above the second and fourth tiers on a 49 in. (1.2 m) spacing, centered in every transverse flue. Face sprinklers were installed 18 in. (46 mm) from the face of the commodity.

Additional IRAS protection details are given in Table 3-9. Figure 3-31 shows the in-rack sprinkler locations with respect to the rack storage arrangement in Test 3.

3.3.4 Test Observations

3.3.4.1 Test 1

Test 1 was initiated by igniting the fuel in the pan using a propane torch at the east face of the main array. The initial flames from the ignition pan reached approximately 1.8 m (6 ft) high. Shortly thereafter, the pallet on the second tier became involved in the fire. The plastic wrap on the first four tiers melted away within the first minute of the test. At 2:13, there was a collapse of three (3) metal cans from the bottom tier above the ignition pan. Shortly after, the flames reached the bottom of the fourth tier. At 2:37, the containers on the floor breached, resulting in a significant increase in fire size. At 3:02, a container ruptured, and a large flame shot through the target. After 3 minutes, flames reached the top of the array. At 3:10, there were three IRAS activations, while a large pool fire continued in the aisle. The fire size continued to grow as did the size of the pool in the aisle. At 5:00, the test was terminated. Hose streams with aqueous film forming foam (AFFF) were applied.

3.3.4.2 Test 3

Test 3 was initiated by igniting the fuel in the pan using a propane torch at the east face of the main array. Shortly after ignition, the ignition pan fire set of face in-rack sprinklers, reducing the fire size and preventing rupture of the metal containers. At 10:00, the test was terminated.

3.3.5 Test Results

3.3.5.1 Test Evaluation Criteria

When dealing with ignitable liquids, the evaluation of fire test results involves the consideration of five key areas. They are:

- Number of Sprinklers Operated
  - This is a measure of what the needed water supply will be. Large sprinkler operating areas may not represent a viable sprinkler design.
- Sprinkler Operation Along the Edge of Ceiling Perimeter
  - All test facilities have limitations on producing a meaningful fire test. Beyond having a large enough volume to represent a large building volume, it is important to recognize that operation of any sprinkler in the last ring of sprinklers indicates that more sprinkler beyond could operate.
- Extent of Fire Damage
  - Fire testing arrays have limitations due to available fuel quantities. The fire spread must be contained within the fuel footprint in the array.
- Steel Temperatures
  - The ceiling temperatures created during a fire represent the level of thermal assault the building structural elements will see. Steel structures will lose strength if heated to

temperatures above 1000°F (540°C). Target steel temperatures directly above a storage array must not exceed a one-minute average of 1000°F (540°C) or a recorded temperature of 1200°F (650°C).

- Pile Collapse
  - This is unique to liquids storage arrays. A pile collapse can result in a large release of liquid and a significant increase in pool fire size.

3.3.5.2 Test 1

Test 1 resulted in twenty-nine (29) ceiling sprinkler activations and seven (7) IRAS activations. After test termination, an additional eleven (11) ceiling and one (1) IRAS activated. The test was terminated five (5) minutes after ignition due to the fire size exceeding the limits established pre-test. Figure 3-35 shows the ceiling sprinkler activation sequence, time, and locations. Figure 3-36 shows the same information for the in-rack sprinklers.

The heat flux to the target during Test 1 is shown in Figure 3-37. Heat fluxes close to 1100 BTU/min/ft^2 (200 kW/m^2) were measured roughly four minutes into the test. At these fluxes, it is expected that the fire would have spread to the target.

Gas and steel temperatures at the ceiling were also measured during the test. Figure 3-38 shows the ceiling gas temperatures and Figure 3-39 shows the structural steel temperatures during Test 1. At the time of test termination, both the ceiling gas and the structural steel temperatures were still rising.

3.3.5.3 Test 3

Test 3 resulted in four (4) IRAS activations, which fully suppressed the fire. Figure 3-40 shows the in-rack sprinkler activation sequence, time, and locations. No ceiling sprinklers activated during the test.

The heat flux to the target during Test 3 is shown in Figure 3-41. The maximum measured heat flux at the target was 74 BTU/min/ft^2 (14 kW/m^2), exceeding 53 BTU/min/ft^2 (10 kW/m^2) in one location for less than ten seconds. These heat flux levels are not expected to be sufficient to cause fire spread across an 8 ft (2.4 m) wide aisle.

Gas and steel temperatures at the ceiling were also measured and both remained relatively low throughout the test and were relatively flat at the time of test termination. Figure 3-42 shows the ceiling gas temperatures and Figure 3-43 shows the structural steel temperatures during Test 3.

3.3.6 Conclusions

The protection scheme for Test 1 was determined to be inadequate. Test 3 showed that the addition of face sprinklers would limit the fire growth and in-rack sprinklers could be used to control the fire.

3.3.7 Figures

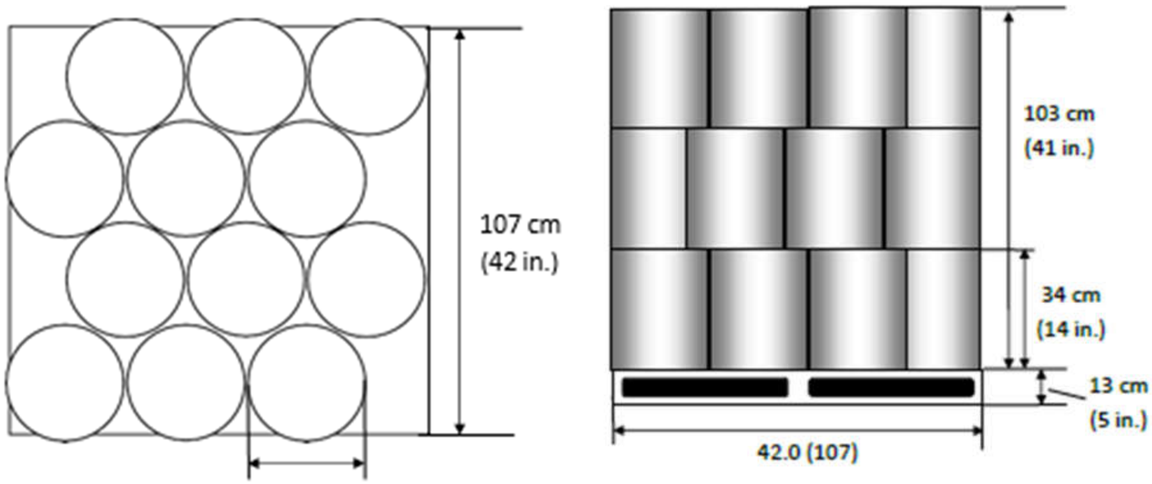


Figure 3-29: Plan view (left) and elevation view (right) of 5 gal (19 L) metal containers placed on a pallet (36 per pallet).

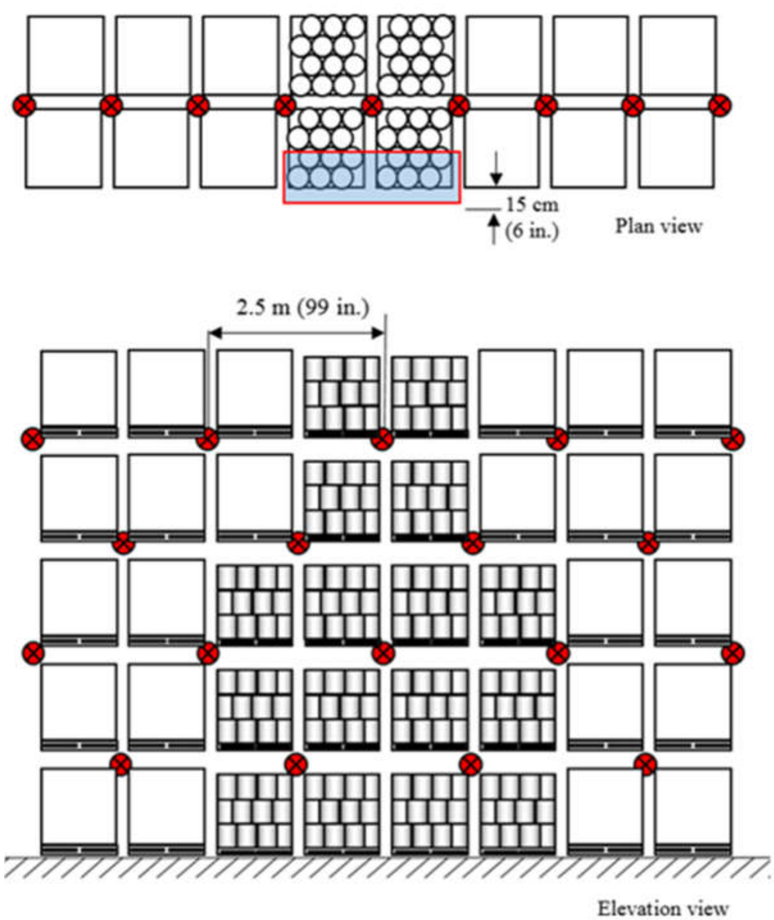


Figure 3-30: Double-row rack storage configuration and IRAS layout for Test 1.

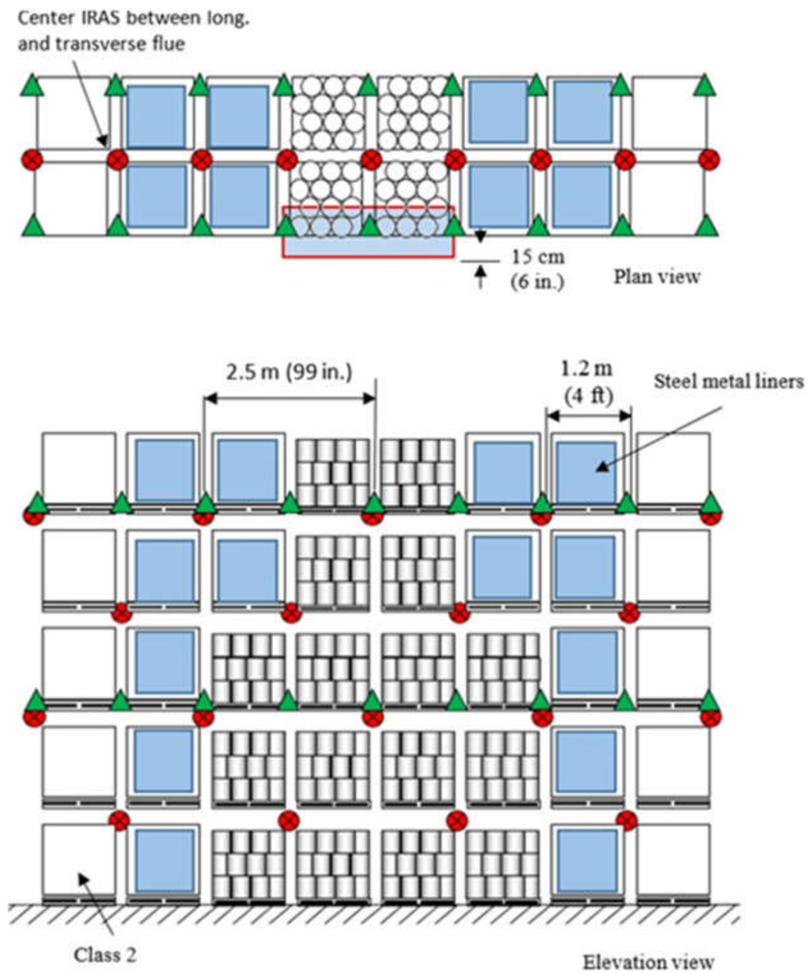


Figure 3-31: Double-row rack storage configuration and IRAS layout for Test 3.

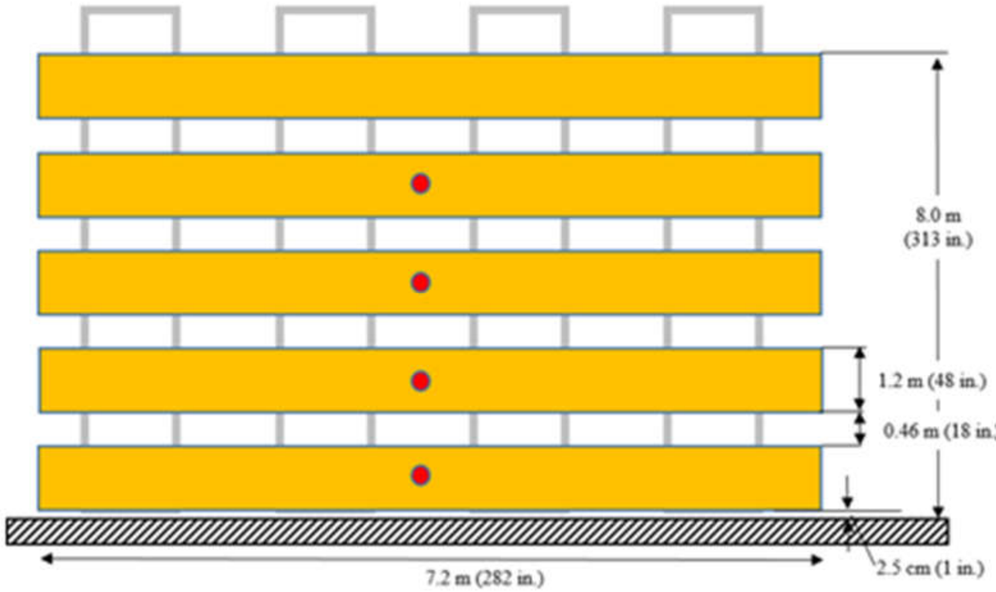


Figure 3-32: Schematic of target array with heat flux gauge locations for Test 1 and Test 3.

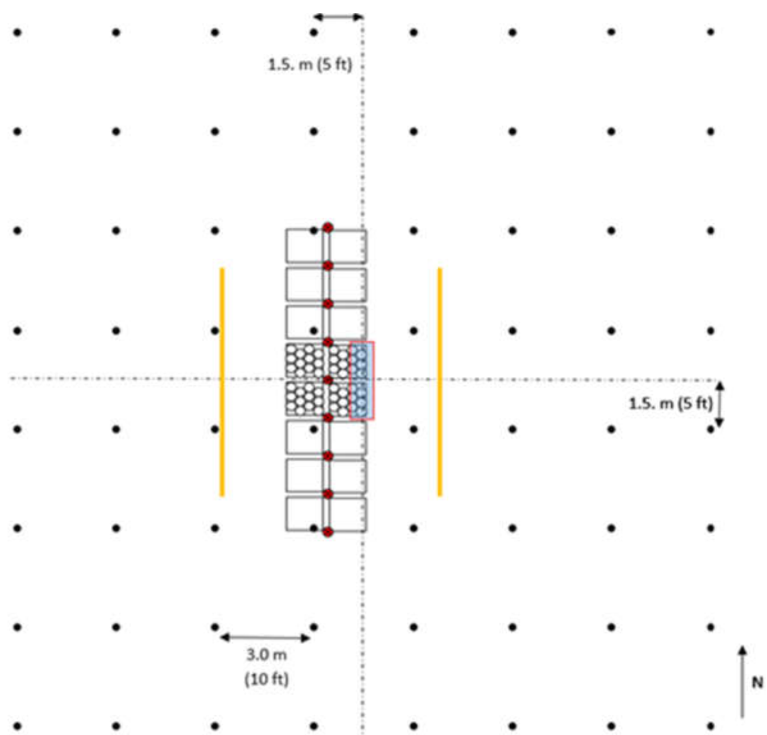


Figure 3-33: Plan view of ceiling sprinkler locations with respect to rack storage for Test 1.

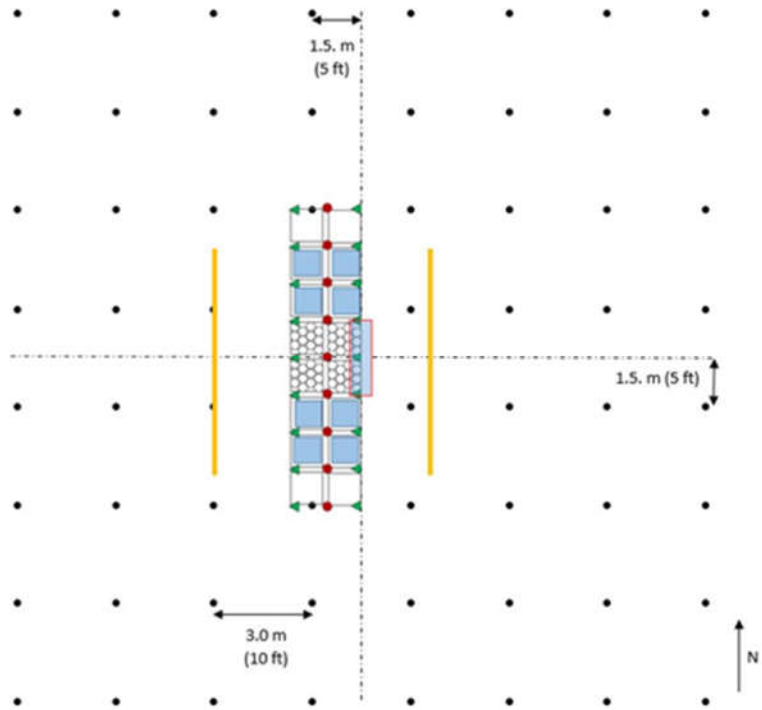
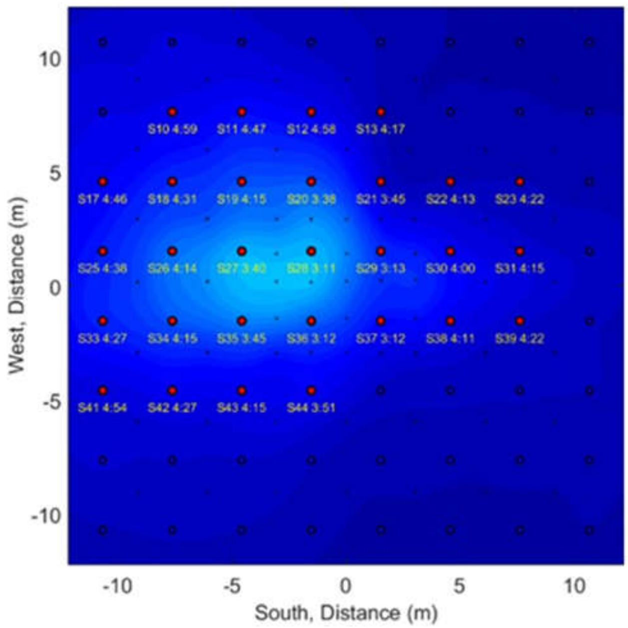


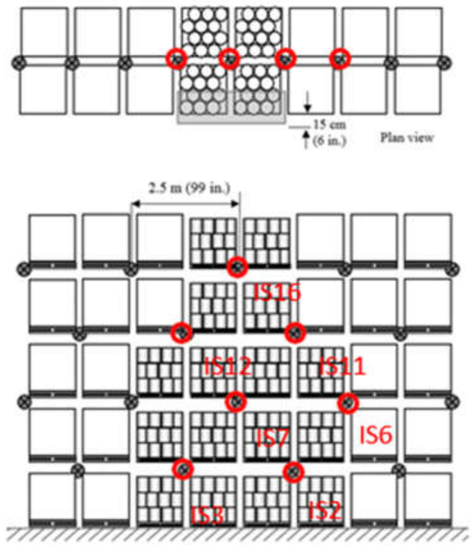
Figure 3-34: Plan view of ceiling sprinkler locations with respect to rack storage for Test 3.

3.3.8 Test Data



Sequence #	Sprinkler ID	Activation Time, mm:ss
5	HEAD28	03:11.5
6	HEAD37	03:12.3
7	HEAD36	03:12.5
8	HEAD29	03:13.0
11	HEAD20	03:38.9
12	HEAD27	03:40.8
13	HEAD35	03:45.2
14	HEAD21	03:45.7
15	HEAD44	03:51.4
16	HEAD30	04:00.2
17	HEAD38	04:11.1
18	HEAD22	04:13.8
20	HEAD26	04:14.8
21	HEAD19	04:15.0
22	HEAD34	04:15.2
23	HEAD31	04:15.4
24	HEAD43	04:15.9
25	HEAD13	04:17.5
26	HEAD23	04:22.0
27	HEAD39	04:22.2
28	HEAD42	04:27.6
29	HEAD33	04:27.9
30	HEAD18	04:31.9
31	HEAD25	04:38.2
32	HEAD17	04:46.2
33	HEAD11	04:47.6
34	HEAD41	04:54.2
35	HEAD12	04:58.1
36	HEAD10	04:59.4

Figure 3-35: Ceiling sprinkler operation for Test 1 – sequence, time and location.



Sequence #	Sprinkler ID	Activation Time, mm:ss
1	IRHEAD07	02:40.4
2	IRHEAD12	02:42.5
3	IRHEAD16	03:05.5
4	IRHEAD02	03:06.7
9	IRHEAD11	03:13.5
10	IRHEAD06	03:31.5
19	IRHEAD03	04:13.8

Figure 3-36: IRAS sprinkler operation for Test 1 – sequence, time and location.

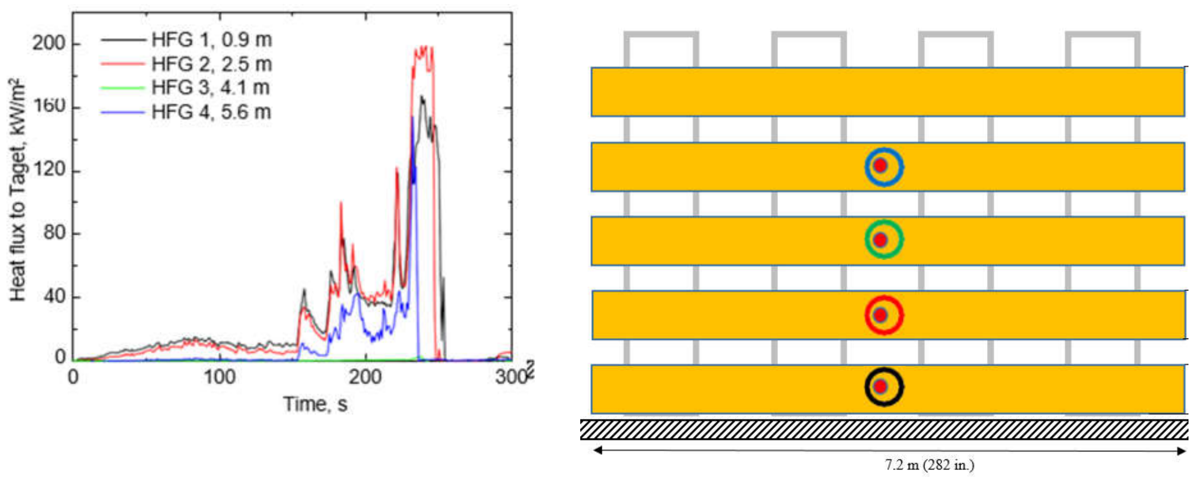


Figure 3-37: Measured heat flux at four elevations in the target array and locations of heat flux gauges in the target array for Test 1.

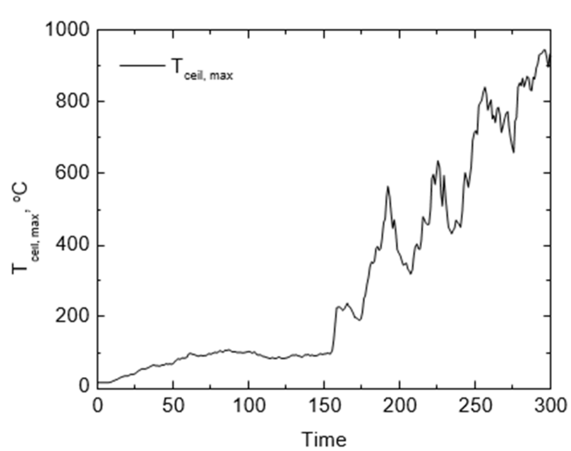


Figure 3-38: Ceiling gas temperature history for Test 1.

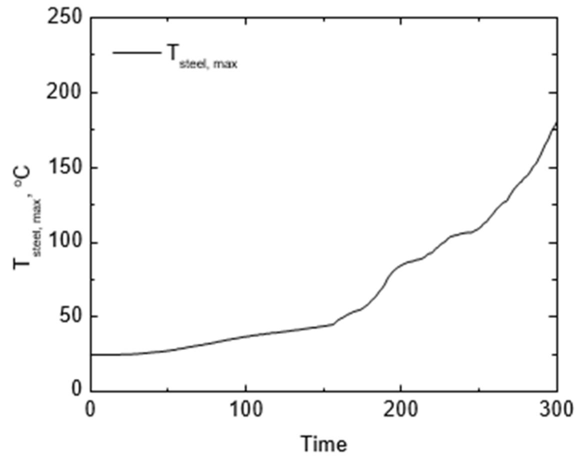
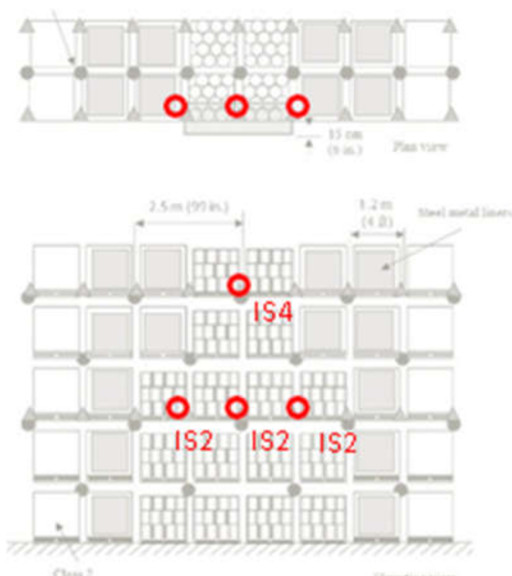
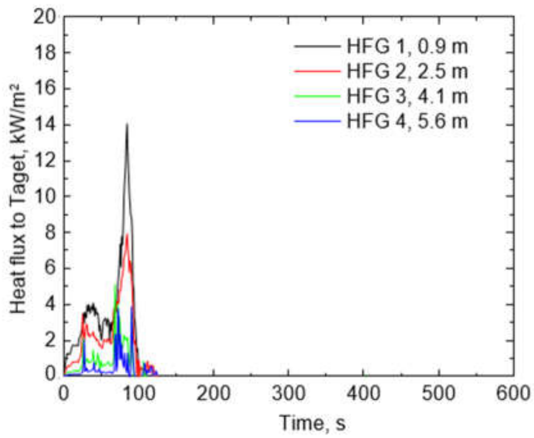


Figure 3-39: Steel temperature history for Test 1.



Sequence #	Sprinkler ID	Activation Time, mm:ss
Ceiling		
1	IRHEAD23	00:18.2
2	IRHEAD24	00:59.7
3	IRHEAD41	01:24.8
4	IRHEAD22	01:38.0

Figure 3-40: Sprinkler operation for Test 3 – sequence, time and location.



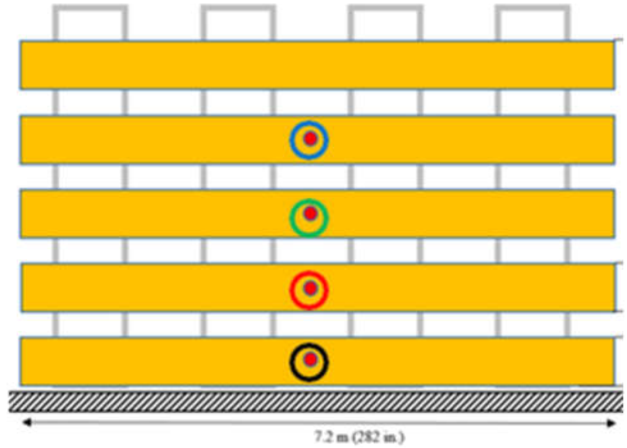


Figure 3-41: Measured heat flux at four elevations in the target array and locations of heat flux gauges in the target array for Test 3.

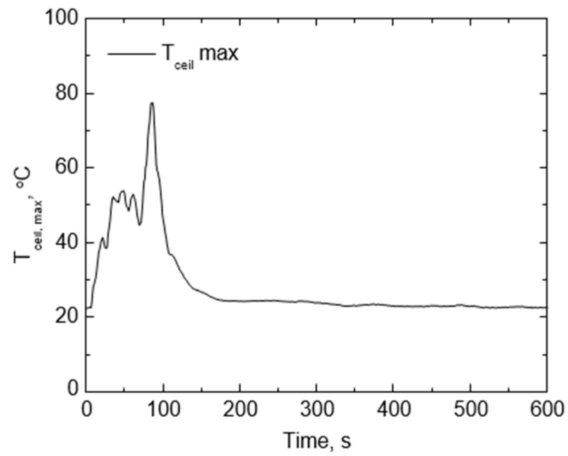


Figure 3-42: Ceiling gas temperature history for Test 3.

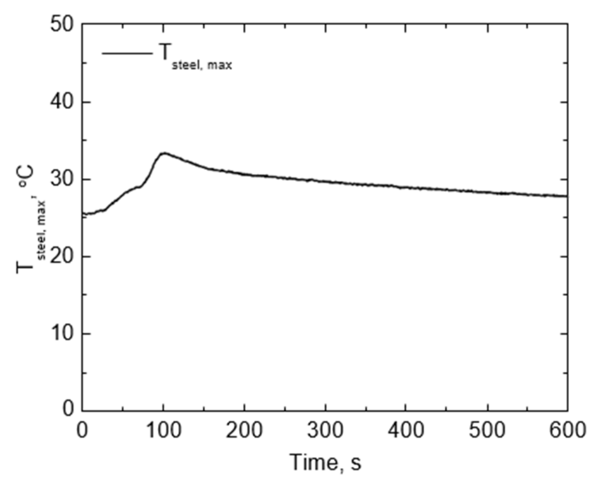


Figure 3-43: Steel temperature history for Test 3.

4. **Conclusions**

The fire test results provided in this report clearly define the hazards of ignitable liquids in metal containers as well as provide very effective protection options for certain liquid-container combinations.

The container size was extended to 6.5 gal (25 L) from 5 gal (19 L). This change is not expected to negatively impact the performance of the tested fire protection. Adding 1.5 gal (5.7 L) per container to an initial spill will not significantly grow the pool fire since it is unlikely that the entire contents of the container can be instantaneously released. The provided protection works by cooling to exposed metal containers. The size increase is also not expected to alter this protection mechanism.

The impact of each test program covered by this report is listed below:

1. Modify protection criteria for palletized liquids in metal containers up to and including 6.5 gal (25 L) [Public Comment #56]

   Fire tests described in Sections 3.1 and 3.2 of this report show that the fire hazard of palletized liquids in metal containers up to and including 6.5 gal (25 L) presents a greater challenge than previously recognized. New protection criteria are proposed in Table 4-1 to replace the existing protection in Table 16.5.2.2 located in NFPA 30, 2021 ed.

Table 4-1: Proposed Protection for Palletized / Solid-Piled Storage of Liquids in Metal Containers Up to and Including 6.5 gal (25 L)

Liquid Flash Point	Maximum Ceiling Height ft (m)	Maximum Storage Height ft (m)	Packaging Type	Ceiling Sprinkler Protection		
				Response/Nominal Temperature Rating/Orientation	K-factor gpm/psi$^{1/2}$ (L/min/bar$^{1/2}$)	Design, density/area or # of Sprinklers @ Pressure psi (bar)
Any	30 (9.1)	5 (1.5)	Uncartoned and/or Cartoned	QR/Ordinary/Any	14.0 (202)	50 @ 18 (1.2)
					16.8 (235)	50 @ 13 (0.9)
					≥22.4 (320)	50 @ 7 (0.5)
		12 (3.7)	Cartoned Only	SR/Ordinary/Any	≥ 11.2 (161)	0.6 gpm/ft^2 over 5000 ft^2 24 mm/min over 460 m^2
				QR/Ordinary/Any	25.2EC (360EC)	26 @ 22 (1.5)

2. Modify protection criteria for uncartoned 5 gal (19 L) metal containers to include face sprinklers [Public Comment #54 to NFPA 30]

   Fire tests described in Section 3.3 of this report show that small metal containers without cartons in racks need face sprinklers in addition to longitudinal flue sprinklers to provide adequate cooling to the containers and prevent an uncontrolled fire. The container size can also be extended up to 6.5 gal (25 L) for rack storage arrays.

https://www.fmglobal.com/research-and-resources/standards-and-certification/code-support-reports