RESEARCH TECHNICAL REPORT

Summary Report of Fire Testing Involving Small Plastic Containers of Low Flash Point Liquids in Rack Storage – for NFPA 30

Summary Report of Fire Testing Involving Small Plastic Containers of Low Flash Point Liquids in Rack Storage

(Document prepared in support of code changes)

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For

NFPA 30 Flammable and Combustible Liquids Code

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Disclaimer

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1. **Introduction**

The term ignitable liquid as used in this report and by FM is defined as 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 Input made to NFPA 30-2027:

Table 1-1: Summary of Code Changes

Public Input No.	NFPA 30 Section	Subject
35	16.5.3.14	Addition of protection criteria for rack storage of liquids in maximum 5 oz. (150 mL) plastic containers

This report was compiled from one (1) full scale fire test program conducted by FM in 2022. The test work was aimed at defining adequate fire protection for the rack storage of non-miscible low flash point ignitable liquids [FP<200°F (93°C)] in 5 oz. (150 mL) cartoned plastic containers.

1.2 Organization of this Report

As noted above, this document contains documentation from one (1) full scale fire test program. Two tests were completed as part of the program, and both are included in this report.

2. **FM Test Facilities Information**

The Fire Technology Laboratory is located at the FM 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.

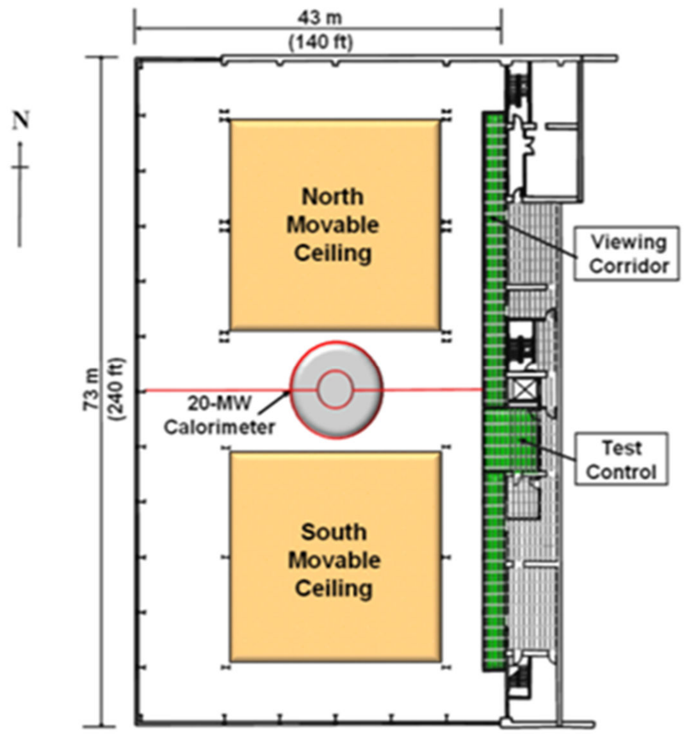

Figure 2-1: Illustration of FM Large Burn Laboratory test locations

3. **Test Summaries**

3.1 Evaluation of In-Rack Sprinkler Protection for Small-Bottle Storage of Low Flash Point Ignitable Liquids / James P. White / May 2022

3.1.1 Test Overview

Two large-scale fire tests were conducted to determine appropriate protection recommendations for rack storage of low flash point ignitable liquids [FP<200°F (93°C)] in 5 oz. (150 mL) cartoned plastic containers.

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 Number	Test 1	Test 2
Commodity Description		
Ignitable Liquid	Heptane	
Bottle Material	PET	
Bottle Size (oz. [mL])	5.0 [148]	
Packaging Arrangement	Corrugated Cartons on Hardwood Pallets	
Carton Moisture Content (mass%, dry basis)	6.0	5.5
Test Configuration		
Storage Arrangement	Open-Frame Rack	Open-Frame Rack
Main Array Size (pallet loads, W×L×H)	2×6×5-tier DRR	2×6×5-tier DRR
Target Array Size (pallet loads, W×L×H)	1×4×5-tier SRR	1×4×5-tier SRR
Aisle Width (ft.-in. [m])	8-0 [2.4]	8-0 [2.4]
Nominal Storage Height (ft.-in. [m])	26-0 [7.9]	26-0 [7.9]
Nominal Ceiling Height (ft.-in. [m])	40-0 [12.2]	40-0 [12.2]
Clearance to Ceiling (ft.-in. [m])	14-0 [4.3]	14-0 [4.3]
Array Centered Below (No. Ceiling Sprinklers)	1	1
Ignition Location	Face, 3rd tier	Face, 3rd tier
Ceiling Sprinkler Protection		
Sprinkler Orientation – upright/pendent (dry/wet)	Upright (dry)	Upright (dry)
Response (QR – quick response)	QR	QR
Discharge Coefficient (K-factor) (gpm/psi$^{1/2}$ [lpm/bar$^{1/2}$])	11.2 [160]	11.2 [160]
Temperature Rating (°F [°C])	155 [68]	155 [68]
Spacing (ft. × ft. [m × m])	10 × 10 [3 × 3]	10 × 10 [3 × 3]
Discharge Pressure (psi [bar])	N/A	N/A
Discharge Density (gpm/ft.^{2} [mm/min.])	N/A	N/A
In-Rack Sprinkler Protection		
Sprinkler Orientation – upright/pendent (dry/wet)	Pendent (wet)	Pendent (wet)
Response (QR – quick response)	QR	QR
Discharge Coefficient (K-factor) (gpm/psi$^{1/2}$ [lpm/bar$^{1/2}$])	8.0 [115]	8.0 [115]
Temperature Rating (°F [°C])	165 [74]	165 [74]
Vertical Spacing (ft.-in. [m]) (Horizontal Barrier?)	11-0 [3.4] (yes)	5-6 [1.7] (yes)
Spacing on line (along longitudinal flue) (ft.-in. [m])	4-0 [1.2]	4-0 [1.2]
Spacing on line (along face) (ft.-in. [m])	4-0 [1.2]	4-0 [1.2]
Discharge Pressure (psi [bar])	50 [3.4]	50 [3.4]
Discharge Flow (gpm [lpm])	57 [214]	57 [214]
Test Results		
First / Final Sprinkler Activation (min:s)	03:28 / 07:53	02:37 / 22:04
Total Sprinklers Activated (Ceiling / IRAS)	0 / 4	0 / 3
Max Ceiling Gas Temperature (°F [°C])	214 [101]	128 [53]
Max 1-min Average Gas Temperature (°F [°C])	151 [66]	91 [33]
Max 1-min Average Steel Angle Temperature (°F [°C])	107 [42]	79 [26]
Aisle Jump (min:s)	N/A	N/A
Test Concluded (min:s)	08:40	45:00
Protection Outcome	Failure	Success

3.1.2 Test Setup

3.1.2.1 Commodity

Commodity for both tests included 5 oz. (150 mL) polyethylene terephthalate (PET) plastic bottles filled with heptane, as shown in Fig. 3-1. The heptane bottles were loosely packaged as a single layer, two bottles wide by three bottles long (six bottles per carton) inside corrugated cardboard cartons measuring 4.25 in. (10.8 cm) wide by 5 in. (12.7 cm) long by 6 in. (15.2 cm) tall (see Fig. 3-1). The cartons were stacked on hardwood pallets, 80 cartons per layer by 7 layers tall (560 cartons per pallet) as shown in Fig. 3-2. Each pallet load of heptane commodity nominally measured 42.5 in. (108 cm) wide by 42.5 in. (108 cm) long by 47 in. (119 cm) tall.

3.1.2.2 Storage Arrangement

3.1.2.2.1 General

Both tests included a main array with a standard double-row rack 6 pallet-loads long by 5 tiers tall. Target arrays were located to the east and west of the main array, separated by 8 ft. (2.4 m) wide aisles. Both target arrays were standard single-row racks 4 pallet-loads long by 5 tiers tall.

The ceiling height was set at 40 ft. (12.2 m). The clearance from ceiling to top of storage was approximately 14 ft. (4.3 m).

3.1.2.2.2 Test 1

The main array for Test 1 included 32 pallet loads of heptane commodity in the core of the array, with an additional 28 pallet loads of FM standard cartoned unexpanded plastic (CUP) commodity included in the top tier and at the ends of the array.

Each target array was filled with 20 pallet loads of CUP commodity. Figures 3-3 through 3-6 show elevation-view diagrams of the main and target arrays, plan-view diagrams of the in-rack and ceiling sprinkler systems, and a photograph viewing the array from the northeast, respectively.

3.1.2.2.3 Test 2

The configuration of Test 2 was identical to that used for Test 1 except for the following:

- The main array included an additional 4 pallet loads of heptane commodity in its bottom tier, replacing the CUP commodity at the ends of the array.

- The east target included an additional 4 pallet loads of heptane commodity in its bottom tier, replacing the CUP commodity in that tier.

Figures 3-7 through 3-11 show elevation-view diagrams of the main and target arrays, plan-view diagrams of the in-rack and ceiling sprinkler systems, and a photograph viewing the array from the northeast, respectively.

3.1.2.3 Ignition Method

For both tests, ignition was accomplished using a single igniter consisting of cotton cellulose material wrapped in cheesecloth, 3 in. (7.6 cm) in diameter, 6 in. (15.2 cm) long, soaked with 8 oz.

(240 mL) of gasoline, and sealed in a clear plastic bag. The igniter was located at the base of the third tier on top of the plywood barrier, at the east face of the main array centered beneath the east side of the pallet immediately north of the central transverse flue, against the left side of the center stringer, 6 in. (15 cm) in from the outer face, as shown in Figures 3-3, 3-4, 3-7 and 3-9. The main array was positioned so that the ignition location was centered under one ceiling sprinkler, offset roughly 39 in. (1.0 m) east and 24 in. (0.6 m) north from ceiling center.

3.1.2.4 Instrumentation

Video cameras were positioned surrounding the array to observe the fire development.

3.1.3 Protection

3.1.3.1 Ceiling Sprinkler Protection

For both tests, a ceiling sprinkler system was installed but was configured as a dry-pipe system with no water delivered during the tests. This configuration was selected to evaluate the independent adequacy of in-rack sprinkler protection without interference from the ceiling sprinklers. If ceiling sprinkler activations were observed, then that information could be used to inform water demand considerations for the recommended protection. The ceiling sprinkler system included QR, K11.2 gpm/psi$^{1/2}$ (K160 lpm/bar$^{1/2}$), 155°F (68°C) rated upright sprinklers installed on a 10×10 ft. (3×3 m) grid, as shown in Figures 3-5 and 3-10. Sprinklers were installed so that their thermal elements were located 6 in. (15 cm) below the ceiling.

3.1.3.2 In-Rack Sprinkler Protection – Test 1

Protection for Test 1 included an in-rack automatic sprinkler (IRAS) system with quick-response (QR), K8.0 gpm/psi$^{1/2}$ (K115 lpm/bar$^{1/2}$), 165°F (74°C) rated pendent sprinklers operating at a discharge pressure of 50 psi (3.4 bar) to provide a nominal water flow rate of 57 gpm (214 lpm) per sprinkler.

The main array included plywood barriers and IRAS installed above the second and fourth tiers. The outer edges of the plywood barriers were flush with the outer face of the heptane commodity. Otherwise, the barriers were continuous across all longitudinal and transverse flues except for a roughly 3 in. (8 cm) gap at each transverse flue containing rack uprights.

Three lines of IRAS were installed above the second and fourth tiers, beneath the horizontal plywood barriers, with one line in the longitudinal flue and one line at each array face (see Figures 3-3 and 3-4). IRAS were centered at each transverse flue at roughly 4 ft. (1.2 m) linear spacing between each sprinkler, with deflectors located 6 in. (15 cm) above the top surface of the heptane commodity. The face IRAS pipes were located flush against the inside edges of the rack uprights so that the face IRAS were recessed roughly 8 in. (20 cm) from the outer face of the array.

3.1.3.3 In-Rack Sprinkler Protection – Test 2

The in-rack protection arrangement for Test 2 was identical to that used for Test 1 except for the following:

- IRAS were installed above every tier (first through fourth tiers instead of only the second and fourth tiers), beneath horizontal plywood barriers, with one line in the longitudinal flue and one line at each array face (see Figures 3-7 and 3-9).
- A plywood barrier and line of face IRAS was added in the east target above its bottom tier (see Figures 3-8 and 3-9).

3.1.4 Test Observations

3.1.4.1 Test 1

Observations of the fire development during Test 1 are summarized in the following. Figure 3-12 includes selected photographs depicting fire development. Figures 3-13 and 3-14 respectively present plan-view and elevation-view diagrams showing sprinkler activation times and locations and the extent of fire damage throughout the array.

Following ignition, the fire developed slowly at the base of the ignition pallet, with flames reaching up the east face to the top of that pallet by about 02:20. Individual bottles began to fall from the ignition pallet into the east aisle at 02:40, initiating and fueling small pool fires in the aisle. By that time, flames at the east face of the ignition pallet were just beginning to reach into the fourth tier. Spillage of individual bottles from the ignition pallet continued to feed the pool fire forming in the aisle, which began to rapidly intensify around 03:20. By 03:30, flames covered all four lower tiers and were beginning to reach into the fifth tier. At that time, the first two IRAS activated at the east face in the central transverse flue in both the fourth and second tiers (respective activation times 03:28 and 03:31).

At 03:45, multiple (4-6) cartons full of bottles fell from the ignition pallet into the east aisle, leading to a brief, but significant increase in fire size in the east aisle. Water spray from the two active IRAS appeared to initially suppress the fire in the second and third tiers so that the dominant fire activity was now at the base of the first tier in the east aisle. However, cartons full of bottles continued to collapse out of the first tier (04:05) and second tier (04:12) pallets, 4-6 cartons at a time, providing additional fuel for the pool fire in the aisle, which began to slowly grow and spread northward.

By 05:00, the pool fire had spread one pallet load to the north and flames again covered all four lower tiers, reaching into the base of the fifth tier. Shortly after, the third IRAS activated at the east face in the second tier 4 ft. (1.2 m) north of the central transverse flue. That IRAS provided only marginal suppression effect, briefly pausing the northward spread of the pool fire. Cartons continued to fall from the first and second tiers into the aisle providing additional fuel to the pool fire, which began spreading to the east. By 05:50, the pool fire spread across the 8 ft. (2.4 m) aisle and flames began licking at the surrogate commodity at the north end of the east target, though the target did not ignite.

By 07:00, fire had spread into the surrogate commodity in the first-tier east row at the north end of the main array, indicating uncontrolled fire spread in the main array. A fourth IRAS activated at 07:53 at the east face in the fourth tier 8 ft. (2.4 m) north of the central transverse flue but did not provide meaningful suppression of the pool fire in the aisle. At 8:40, the test was terminated, and hose streams were applied.

3.1.4.2 Test 2

Observations of the fire development during Test 2 are summarized in the following. Figure 3-15 includes selected photographs depicting fire development. Figures 3-16 and 3-17, respectively, present plan-view and elevation-view diagrams showing sprinkler activation times and locations and the extent of fire damage throughout the array.

Initial fire development was similar to that observed during Test 1. The fire developed slowly with flames reaching up the east face to the top of the ignition pallet by about 01:15. Individual bottles began to fall into the east aisle at 02:18, initiating and fueling small pool fires in the aisle. The first IRAS activated at 02:37, nearly one minute earlier than the first IRAS activation in Test 1. This IRAS was located at the east face, 4 ft. (1.2 m) north of the central transverse flue in the third tier. By that time, fire in the main array was limited to the east face of the ignition pallet, though a substantial pool fire was beginning to form in the east aisle. Water spray from the first IRAS effectively controlled the fire in the ignition pallet and prevented ignition of the lower-tier pallets exposed to the pool fire. By 03:30, the pool fire had largely burned itself out and only residual burning remained confined to the ignition pallet. There was no notable change in fire condition over the next several minutes, other than occasional flare-ups in the ignition pallet due to ruptured bottles, and occasional minor spillage of individual bottles into the aisle with associated small pool fires that quickly burned out without contributing to fire spread.

At 15:43, 16:28, and 17:00, there were significant collapses of burning material from the ignition pallet into the east aisle, each including several cartons full of bottles. These spilled materials initiated and sustained a pool fire located predominantly at the base of the main array but extending as far as 7.5 ft. (2.3 m) toward the east target. By 17:40, the pool fire had spread to the first-tier pallet under ignition in the main array.

Over the following few minutes, the fire in the east aisle continued to grow, fed by spillage from the now-involved first-tier pallet and eventually spreading into the second-tier pallet under ignition. The second and third IRAS activated at 22:03 and 22:04, both at the east face 4 ft. (1.2 m) north of the central transverse flue, in the second and first tiers respectively. Water spray from those sprinklers rapidly suppressed the fires in the main array and east aisle, so that only residual burning remained in the ignition pallet, the two pallets below ignition in the first and second tiers, and in the spilled material in the east aisle. The active IRAS were not able to fully extinguish the burning heptane but could control the fire activity and maintain this steady condition for the duration of the test until the test was terminated at 45:00 and hose streams were applied.

3.1.5 Test Results

3.1.5.1 Ceiling Temperatures

In Test 1, the maximum ceiling gas temperature was 214°F (101°C), measured at ceiling center (roughly 3 ft. [0.9 m] west and 2 ft. [0.6 m] south of ignition) immediately prior to the third IRAS activation around 05:08. The maximum one-minute average ceiling gas temperature was 151°F (66°C), also measured at ceiling center around the same time at 05:14. The maximum one-minute average ceiling steel temperature was 107°F (42°C), measured at ceiling center around 08:31, just before test termination.

In Test 2, the maximum ceiling gas temperature was 128°F (53°C), measured at ceiling center around 17:00, coinciding with a brief flare-up of the pool fire after a significant collapse of burning material into the aisle. The maximum one-minute average ceiling gas temperature was 91°F (33°C), measured 5 ft. (1.5 m) west and 5 ft. (1.5 m) north of ceiling center around 21:40, just prior to the second and third IRAS activations. The maximum one-minute average ceiling steel temperature was 79°F (26°C), measured at ceiling center around 22:23, just after the second and third IRAS activations.

3.1.5.2 Sprinkler Activations

No ceiling sprinklers activated in either test, consistent with the relatively low gas temperatures measured near the ceiling during both tests.

In Test 1, four IRAS activated during the test (two per tier) and a fifth IRAS activated shortly after test termination (at 8:54 in the second tier at the north end in the longitudinal flue). In Test 2, three IRAS activated (one per tier) and controlled the fire throughout the 45:00 duration of the test.

3.1.5.3 Fire Spread in Main Array

For both tests, there was no notable direct fire spread from the ignition pallet westward across the longitudinal flue or to the adjacent pallets to the north or south. All observed fire spread was driven by spillage of burning material from the ignition pallet leading to the formation of a pool fire in the aisle. Spillage and initiation of the pool fire occurred prior to IRAS activations in both tests and even after IRAS activations, the pool fire was not easily suppressed.

In Test 1, IRAS did not activate until the pool fire had grown to a significant size and had already spread into commodity in the lower tiers of the main array. Additional spillage from those lower tiers continued to feed the pool fire until it spread beyond the limits of the array, involving surrogate commodity at the northeast end of the main array. Additional IRAS activations failed to control the spreading pool fire.

In Test 2, the protection design included IRAS located closer to the ignition location (directly above the third tier). The difference in IRAS layout led to IRAS activating nearly a minute earlier in Test 2 than in Test 1. With its earlier activation, water spray from the initial IRAS in Test 2 was able to prewet commodity in the lower tiers and prevent their ignition while the initial pool fire burned out, significantly reducing the overall amount of commodity involved in the fire.

In both tests, a rapid escalation in fire severity occurred immediately following sudden collapses of several cartons full of bottles from the ignition pallet, which spurred significant intensification of the pool fire. In Test 1, such collapse events began relatively early at 03:45, shortly after the initial IRAS activations, whereas in Test 2, a significant collapse did not occur until 15:43, more than 13 minutes after the initial IRAS activation. In that time, a considerable amount of water spray had already flowed through and prewetted the commodity in the lower tiers so that when the collapse and subsequent pool fire intensification occurred, the fire had difficulty establishing and spreading in the lower tiers.

No notable upward fire spread beyond the ignition pallet was observed in either test. In both cases, commodity in the fourth tier experienced only superficial damage including melted outer plastic wrap and charring of some of the exposed cartons at the east face. No ignitable liquids from the fourth tier were involved in either fire. In both tests, however, there was significant downward fire spread involving multiple tiers of commodity below the plywood barrier under ignition, including IRAS activations in the lower tiers.

3.1.5.4 Fire Spread to Target

Fire did not spread to either the east or west target arrays during either test. However, in Test 1, the commodity in the bottom tier at the north end of the east target eventually ignited after test termination and before final extinguishment was achieved.

Furthermore, in both tests, spillage of commodity from the third-tier ignition pallet regularly spread as far as 5 to 6 ft. (1.5 to 1.8 m) into the 8-ft. (2.4-m) aisle and the pool fire that formed from that spillage occasionally reached across the full width of the aisle.

3.1.5.5 Pool Fire Activity

Pool fire activity was observed in the east aisle throughout both tests. In Test 1, this activity was intermittent, fluctuating and driven primarily due to spillage and collapse events from the burning pallets in the main array. Eventually, the rate of spillage into the aisle outpaced the burning rate of the spilled ignitable liquids, so that the pool fire proceeded to grow and spread uncontrolled beyond the limits of the test array.

In Test 2, the pool fire activity was again intermittent, fluctuating and driven by spillage and collapse of burning materials from the main array. In this case, however, the rate of spillage was significantly lower due to overall lesser burning in the main array. As a result, the pool fire consistently burned itself out and at no point spread significantly beyond the pile of spilled material in the east aisle.

3.1.5.6 Final Extinguishment

Water spray from the IRAS was not able to fully extinguish the heptane burning in either the pallets in the main array or in the spilled material on the floor in the aisle. In both tests, foam application via firefighter hose streams was required to achieve final extinguishment. In the case of Test 1, which experienced more extensive fire spread leading to deep-seated burning, manual dismantling of the commodity in combination with foam application was required.

3.1.6 Conclusions

3.1.6.1 Evaluation Criteria

Adequacy of protection in each test was evaluated based on the following criteria:

- Ceiling temperatures – measured ceiling-steel temperatures must not exceed a peak value of 1200°F (649°C) or a one-minute average value of 1000°F (538°C).
- Sprinkler activations – the number of sprinkler activations at test termination must provide for a reasonable water demand in the protection system design.
- Fire spread in main array – fire must not spread to either end of the main array nor involve any surrogate commodity.
- Fire spread to target – fire must not spread to the target array.
- Pool fire activity – small pool fires may intermittently form during the test, but a sustained spreading pool fire must not form or must eventually be controlled by the sprinkler protection.

3.1.6.2 Ceiling Temperatures

In both Test 1 and Test 2, ceiling temperatures remained relatively low and were well below failure criteria, indicating that the structural integrity of the ceiling steel was not endangered by the fire in either test. The protection performance with respect to overall building integrity was therefore adequate for Test 2, but inconclusive for Test 1 due to the early termination of that test.

3.1.6.3 Sprinkler Activations

The ceiling sprinkler design used in both tests included quick-response sprinklers and a relatively short clearance of only 6 in. (15 cm) between the sprinkler thermal elements and the ceiling. The observation of no ceiling activations in either test can be considered as a conservative indication that ceiling sprinklers are unlikely to activate during the relevant fire scenarios when the tested in-rack sprinkler protection is used. This validates the intended modular protection design: (1) the in-rack sprinkler system performance can be considered independently from the ceiling sprinkler system; and (2) it is not necessary to combine the water demand between the two systems. It also confirms that ceiling height restrictions do not need to be included in the protection design.

For Test 1, additional IRAS (and possibly ceiling sprinklers) would likely have activated had the test been allowed to continue and therefore the total number of sprinkler activations cannot be conclusively evaluated. For Test 2, the protection performance with respect to sprinkler activations and water demand was adequate.

3.1.6.4 Fire Spread in Main Array

In both Test 1 and Test 2, water spray from the IRAS was able to effectively control the fire in the ignition pallet. All observed fire spread was driven by spillage of burning material from the ignition pallet leading to the formation of a pool fire in the aisle. Overall, the difference in initial IRAS response time, and subsequent prewetting of the commodity in the lower tiers, is likely the most important factor affecting the difference in protection performance observed between Test 1 and Test 2.

There was no notable upward fire spread beyond the ignition pallet in either test. In both tests, however, there was significant downward fire spread involving multiple tiers of commodity below the plywood barrier under ignition, including IRAS activations in the lower tiers. In Test 2, the fire was eventually controlled by the three active IRAS (one per tier up to the ignition tier), with negligible lateral fire spread, no involvement of the surrogate commodity at the ends of the array, and very limited overall fire damage to the commodity.

The implication of the preceding result means that downward fire spread and IRAS activations below the ignition location must be considered in the protection design. A credible worst-case scenario would be one with ignition occurring in the top-most tier of storage that then evolves to include some fire involvement and IRAS activations in every tier of storage below the ignition location. To be effective in such a scenario, the sprinkler design and water demand should consider the potential for IRAS activations over every tier of storage containing the ignitable liquid commodity. The maximum storage height (maximum number of storage tiers) need not be limited so long as sufficient water supply exists at the site to accommodate such a scenario. Subject to these limitations, the protection performance in Test 2 was deemed to be adequate with respect to fire spread in the main array.

3.1.6.5 Fire Spread to Target

Protection performance with respect to this criterion was adequate for Test 2, but inconclusive for Test 1 due to early termination of that test.

Based on the observation of liquids spilling into the aisle, the tested 8 ft. (2.4 m) aisle spacing should be considered as the minimum acceptable separation distance required to prevent fire spread to neighboring storage racks. Wider aisles should be provided where possible, in particular, for taller storage racks where collapse and spillage from higher tiers might spread farther into the aisle upon impacting the floor.

Alternatively, assuming a worst-case scenario where secondary ignition does occur in a neighboring storage rack, based on the protection performance observed during Test 2, it is expected that IRAS activations in the neighboring rack should contain the fire to the bottom tier of that rack. Additional fire spread up or through the neighboring rack is therefore not expected. As a result, the IRAS protection design should consider the potential for activation of additional IRAS in the bottom tier of one neighboring rack.

3.1.6.6 Pool Fire Activity

In Test 1, the pool fire proceeded to grow and spread uncontrolled beyond the limits of the test array. The protection used in Test 1 was deemed to be inadequate.

In Test 2, the pool fire consistently burned itself out and at no point spread significantly beyond the pile of spilled material in the east aisle. The protection used in Test 2 was deemed to be adequate.

3.1.6.7 Final Extinguishment

Prompt fire department response will be necessary to achieve final extinguishment in combination with the recommended IRAS protection. The 45:00 duration of Test 2 should cover the typical fire department response time expected for most sites in all but the most extreme cases.

3.1.7 Figures

Figure 3-1: Photograph showing typical heptane bottle and carton.

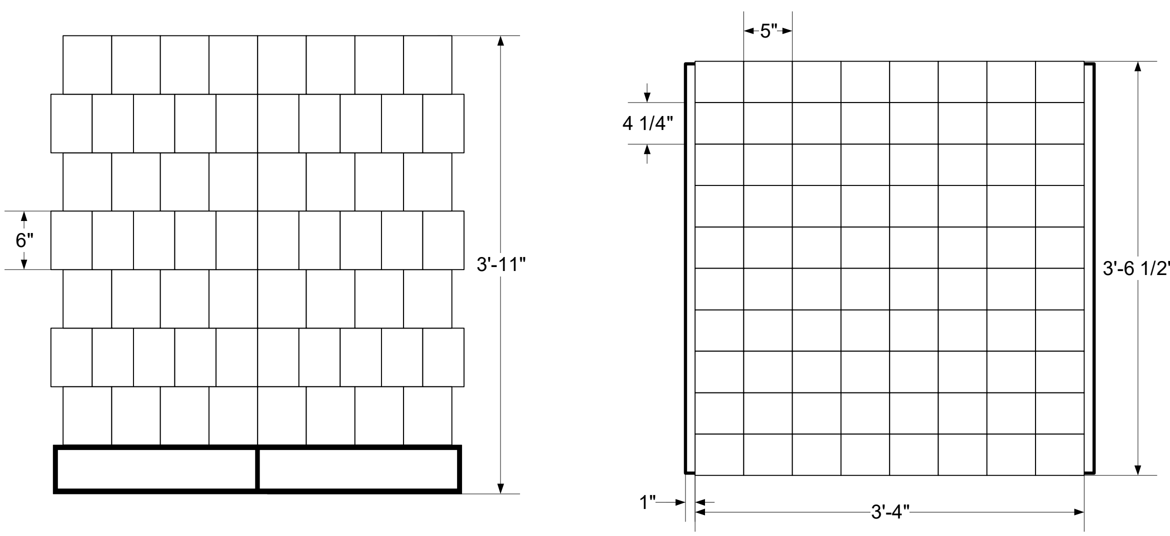

Figure 3-2: Schematic detailing typical pallet load of heptane commodity.

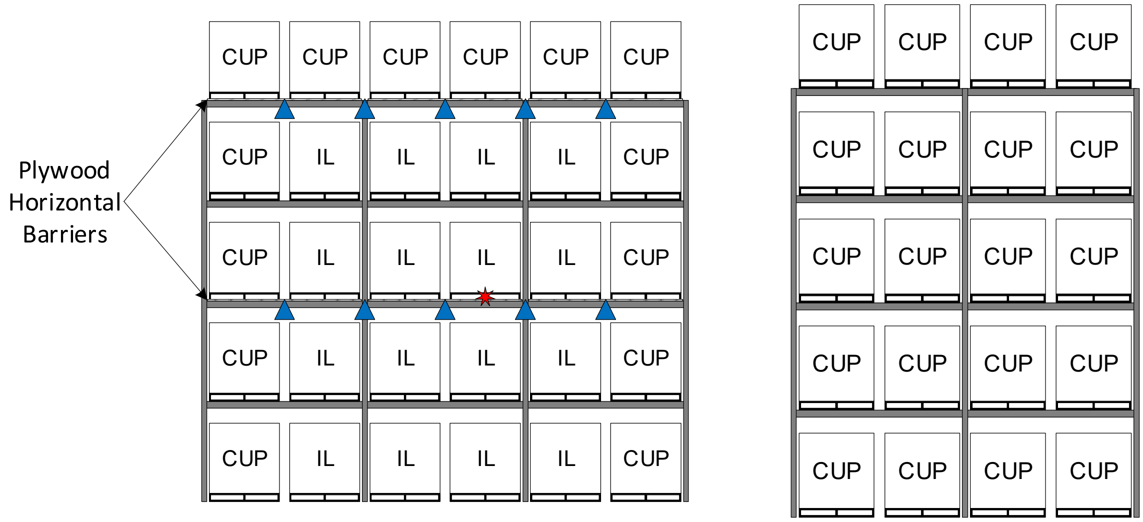

Figure 3-3: Elevation views of the main array (left) and target arrays (right) for Test 1; IL/CUP labels indicate heptane/CUP commodities; blue triangles mark face IRAS locations; red star marks igniter location.

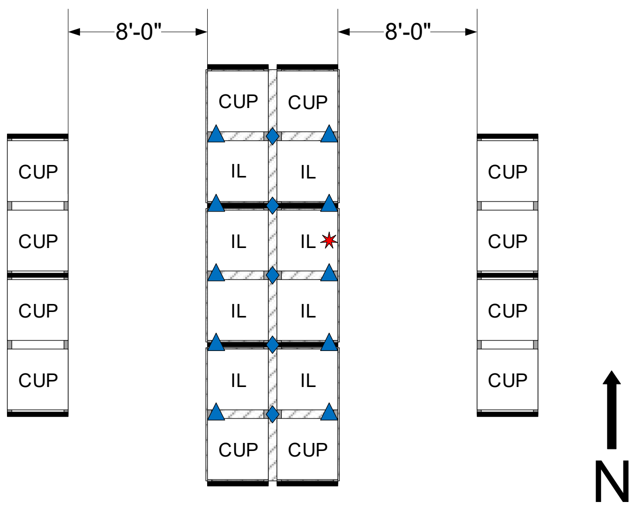

Figure 3-4: Plan view showing IRAS layout for Test 1; IL/CUP labels indicate heptane/CUP commodities; blue diamonds/triangles mark flue/face IRAS locations; red star marks igniter location.

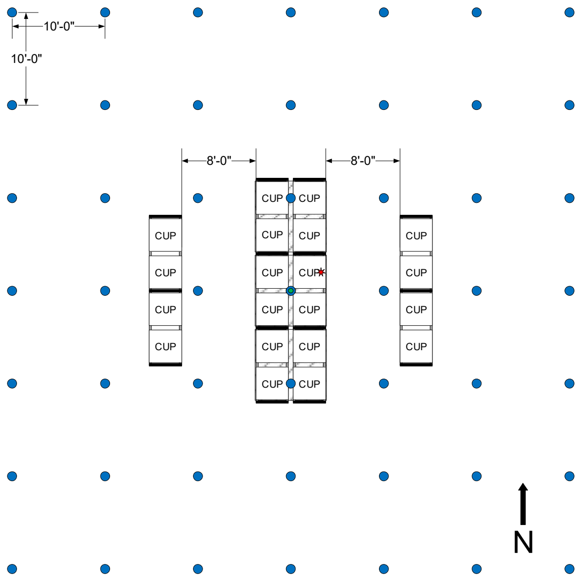

Figure 3-5: Plan view showing ceiling sprinkler layout for Test 1; CUP labels indicate CUP commodity (top-tier only); blue circles mark sprinkler locations; red star marks igniter location.

Figure 3-6: Photograph viewing Test 1 array from the northeast.

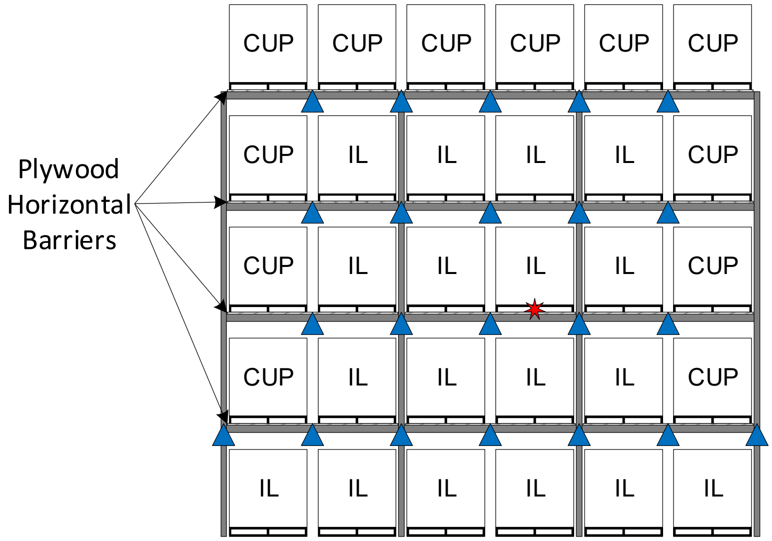

Figure 3-7: Elevation view of the main array for Test 2; IL/CUP labels indicate heptane/CUP commodities; blue triangles mark face IRAS locations; red star marks igniter location.

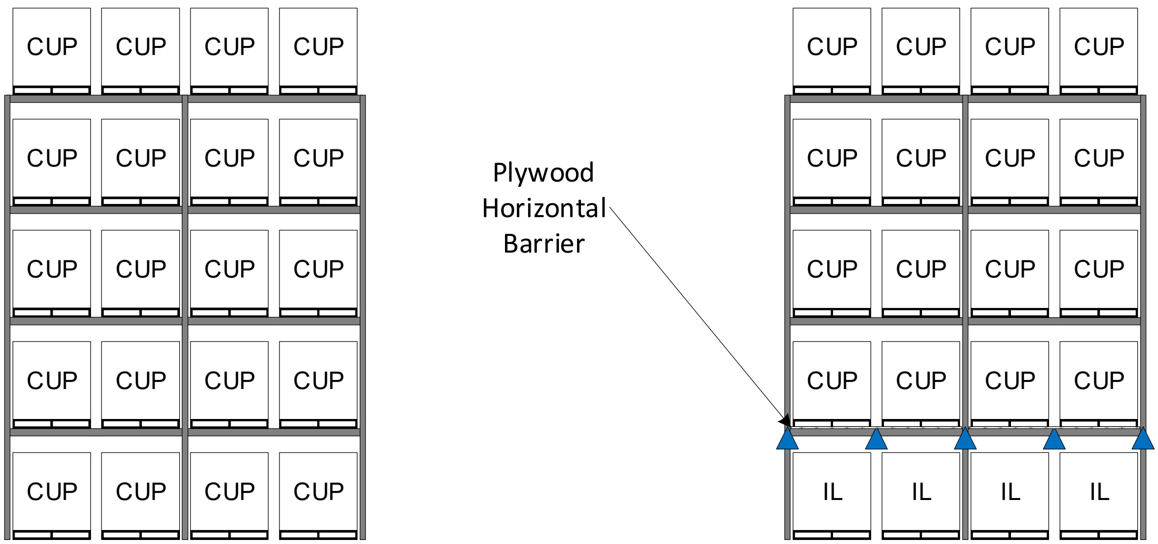

Figure 3-8: Elevation views of the west (left) and east (right) targets for Test 2; IL/CUP labels indicate heptane/CUP commodities; blue triangles mark face IRAS locations.

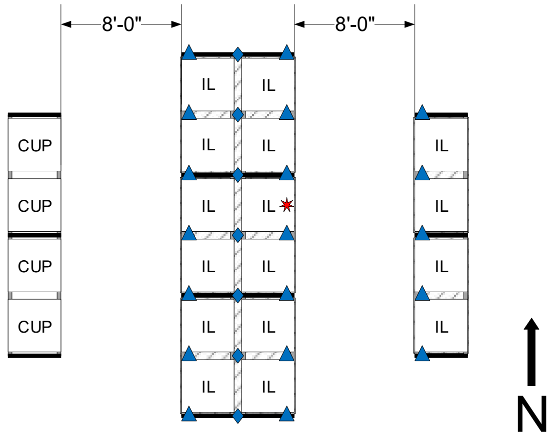

Figure 3-9: Plan view showing IRAS layout for Test 2; IL/CUP labels indicate heptane/CUP commodities; blue diamonds/triangles mark flue/face IRAS locations; red star marks igniter location.

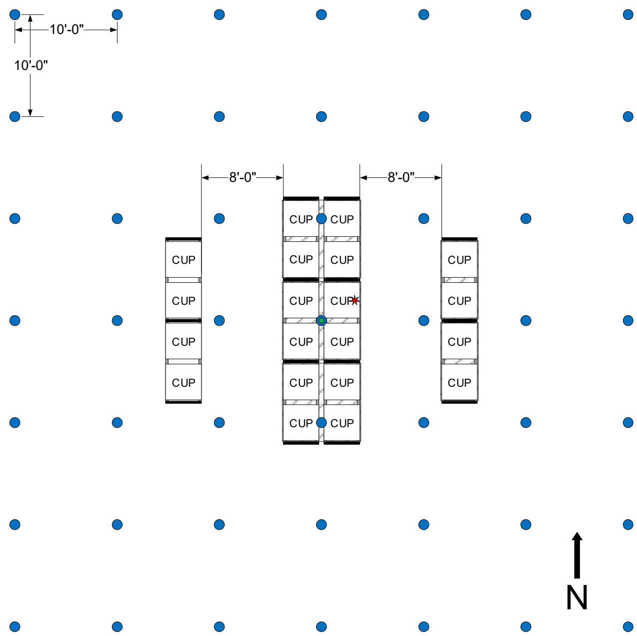

Figure 3-10: Plan view showing ceiling sprinkler layout for Test 2; CUP labels indicate CUP commodity (top-tier only); blue circles mark sprinkler locations; red star marks igniter location.

Figure 3-11: Photograph viewing Test 2 array from the northeast.

3.1.8 Test Data

Figure 3-12: Selected photographs showing fire development during Test 1.

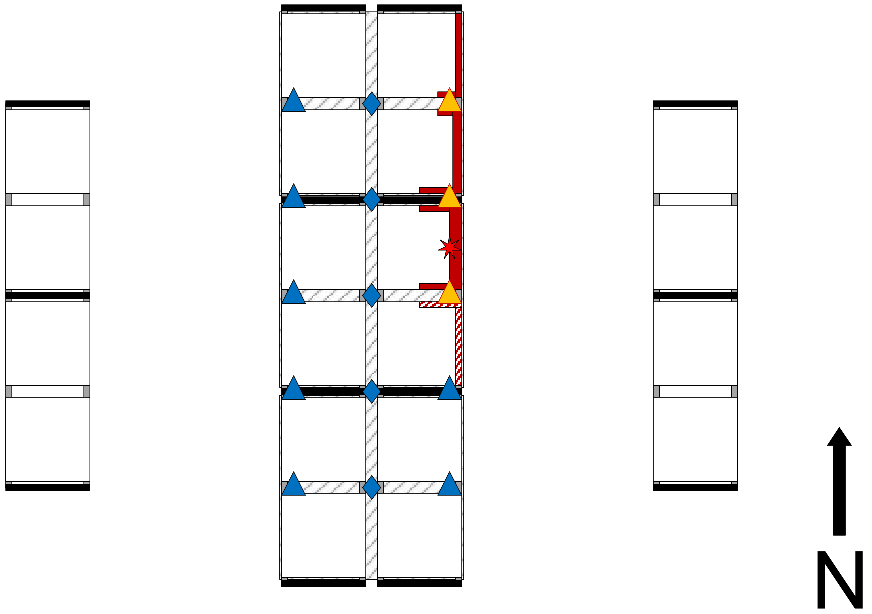

Figure 3-13: Overall plan view of test array showing sprinkler activations (yellow triangles) and extent of fire spread (red shading) during Test 1; solid shaded areas indicate fire damage; diagonal shaded areas indicate superficial charring or melted plastic wrap.

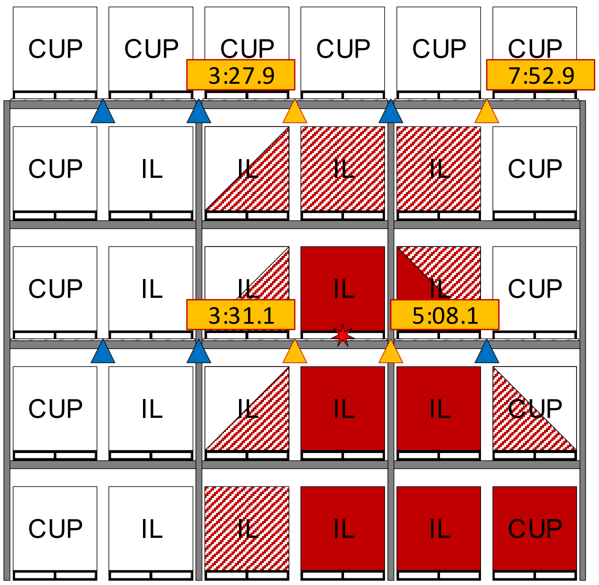

Figure 3-14: Elevation view of main array east face showing sprinkler activations (yellow triangles) and extent of fire spread (red shading) during Test 1; solid shaded areas indicate fire damage; diagonal shaded areas indicate superficial charring or melted plastic wrap.

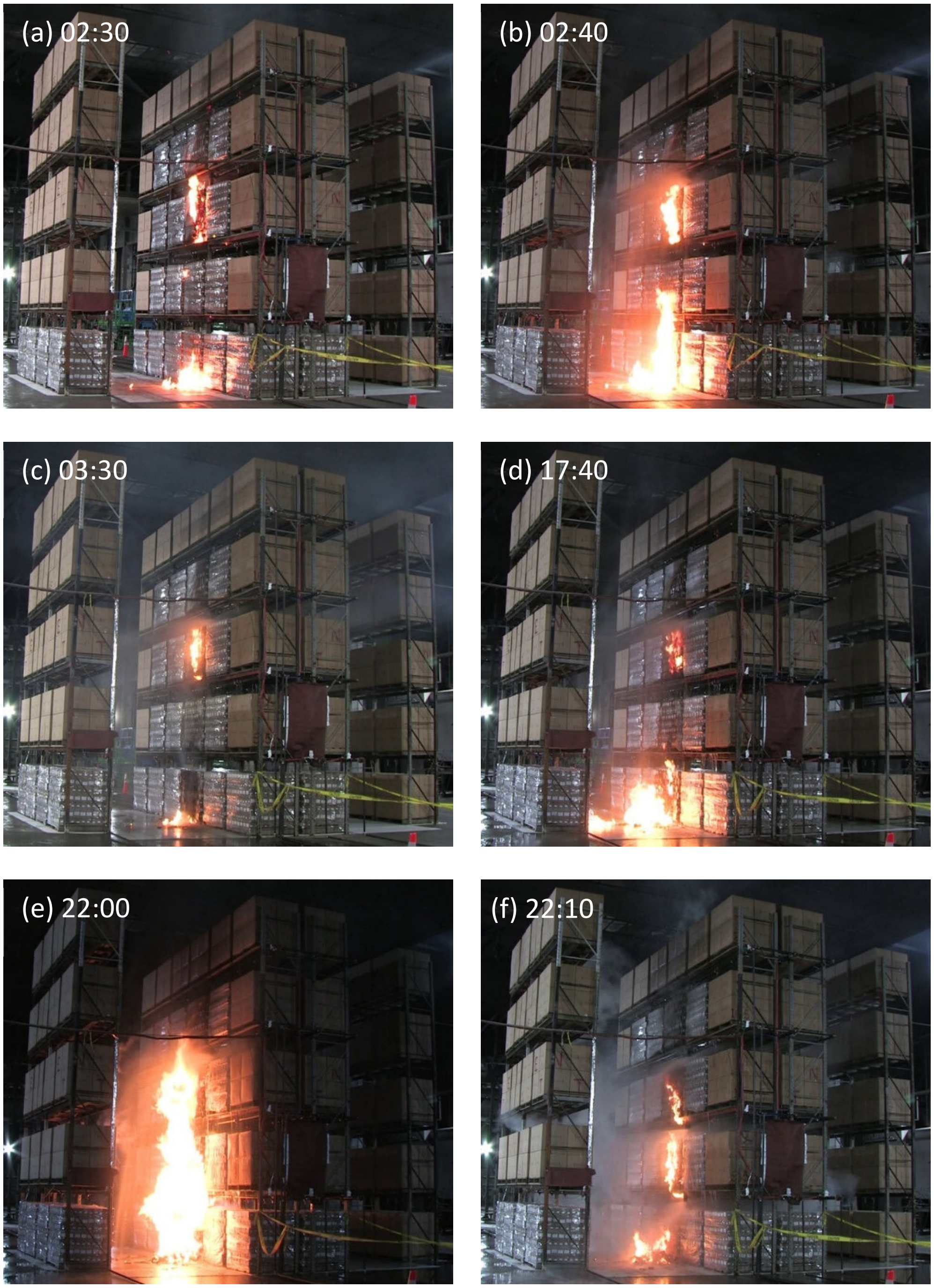

Figure 3-15: Selected photographs showing fire development during Test 2.

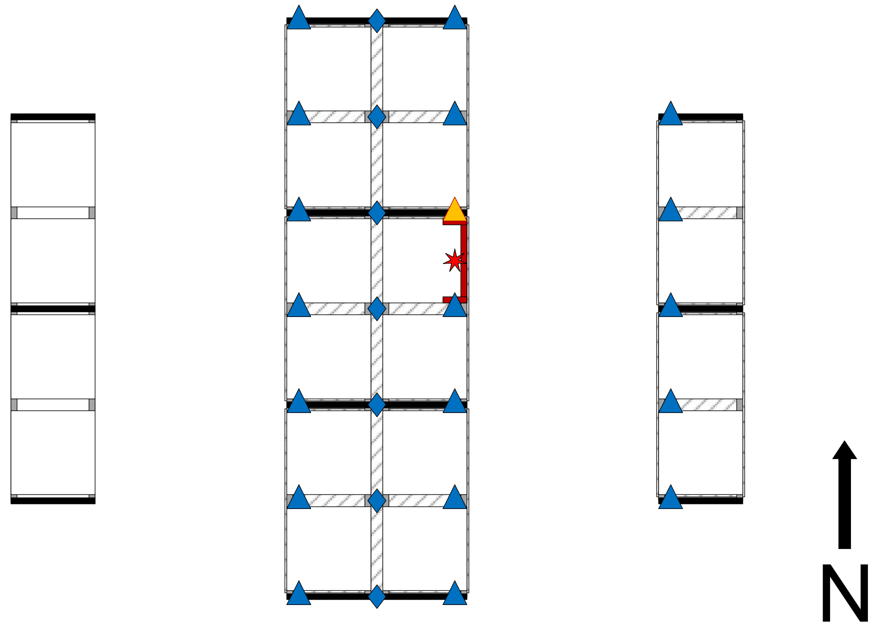

Figure 3-16: Overall plan view of test array showing sprinkler activations (yellow triangles) and extent of fire spread (red shading) during Test 2; solid shaded areas indicate fire damage.

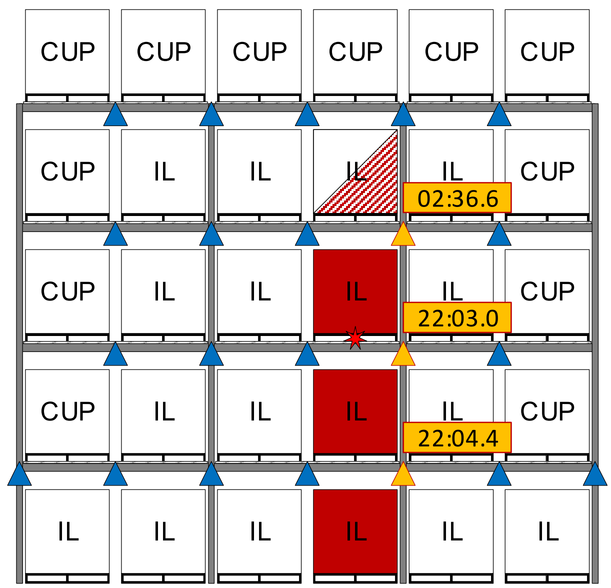

Figure 3-17: Elevation view of main array east face showing sprinkler activations (yellow triangles) and extent of fire spread (red shading) during Test 2; solid shaded areas indicate fire damage; diagonal shaded areas indicate superficial charring or melted plastic wrap.

4. **Code Change Conclusions**

The fire tests provided in this report clearly define the hazards of rack storage of non-miscible low flash point ignitable liquids [FP<200°F (93°C)] in 5 oz. (150 mL) cartoned plastic containers. The following update is proposed for NFPA 30, Section 16:

16.6.X Fire Protection Scheme "G"

16.6.X.1 Horizontal barriers of plywood having a minimum thickness of 3⁄8 in. (10 mm) or of sheet metal of minimum 22-gauge thickness shall be installed in accordance with Figure 16.6.X.1(a), Figure 16.6.X.1(b), or Figure 16.6.X.1(c), whichever is applicable. All ignitible (flammable or combustible) liquid storage shall be located beneath a barrier.

16.6.X.2 In-rack sprinklers shall be installed in accordance with Figure 16.6.X.1(a), Figure 16.6.X.1(b), or Figure 16.6.X.1(c), whichever is applicable.

16.6.X.3 Vertical barriers shall not be provided between in-rack sprinklers.

16.6.X.4 In-rack sprinklers shall meet the following requirements:

(1) In-rack sprinklers shall be ordinary temperature-rated, quick-response sprinklers and shall have a nominal K-factor equal to or greater than 8.0. Intermediate-temperature sprinklers shall be used where ambient conditions require.

(2) In-rack sprinklers shall be installed below each barrier level.

(3) In-rack sprinklers shall provide a minimum operating flow of 60 gpm (227 L/min) out of each of the hydraulically most remote six sprinklers (six on one line or three on two lines) if one barrier level is provided, or out of each of the hydraulically most remote eight sprinklers (eight on one line or four on two lines on the same level) if two or more barrier levels are provided. For each horizontal barrier level beyond eight, add one additional in-rack sprinkler to the demand (add the additional in-racks at the top level of the rack). The minimum in-rack sprinkler discharge pressure shall not be less than a gauge pressure of 10 psi (0.69 bar).

16.6.X.5 Where adjacent rack bays are not dedicated to storage of ignitible (flammable or combustible) liquids, the barrier and in-rack sprinkler protection shall be extended at least 8 ft. (2.4 m) beyond the area devoted to ignitible (flammable or combustible) liquid storage.

16.6.X.6 If there are adjacent rack bays that are not dedicated to storage of Class IB, Class IC, Class II, and Class IIIA Liquids [FP < 200°F (93°C) and BP ≥ 100°F (37.8°C)] ignitible (flammable or combustible) liquids in plastic containers of 5 oz. (150 ml) or less stored in cartons, the protection shall be extended as follows:

(1) A minimum aisle width of 10 ft. (3.0 m)

(2) A minimum aisle width of 8 ft. (2.4 m) and balance the Scheme G protection with the protection needed for the adjacent rack, including when the racks are protected with Scheme A or Scheme B.

(3) A minimum aisle width of 8 ft. (2.4 m) and provide a line of face sprinklers, spaced 4-5 ft. (1.2 – 1.5 m) on center, at the 10 ft. (3.0) elevation. Design the face sprinklers for six (6) sprinklers operating, each discharging 30 gpm (114 L/min). Balance this demand with Scheme G protection.

16.6.X.7 Ceiling sprinklers shall meet the following requirements:

(1) Ceiling sprinklers shall be designed to protect the surrounding occupancy.

(2) Ceiling sprinkler water demand shall not be included in the hydraulic calculations for the in-rack sprinkler protection.

(3) Any sprinkler type shall be acceptable for the ceiling sprinkler protection.

(4) If standard spray sprinklers are used, they shall be capable of providing not less than 0.20 gpm/ft.^{2} over 3000 ft.^{2} (8 L/min over 270 m^2).

(5) If the ignitible (flammable or combustible) liquid storage does not extend to the full height of the rack, protection for commodities stored above the top horizontal barrier shall meet the requirements of NFPA 13 for the commodities stored, based on the full height of the rack.

16.6.X.8 A 500 gpm (1900 L/min) hose stream allowance shall be provided.

16.6.X.9 A 1-hour duration shall be provided for the fire protection water demand.

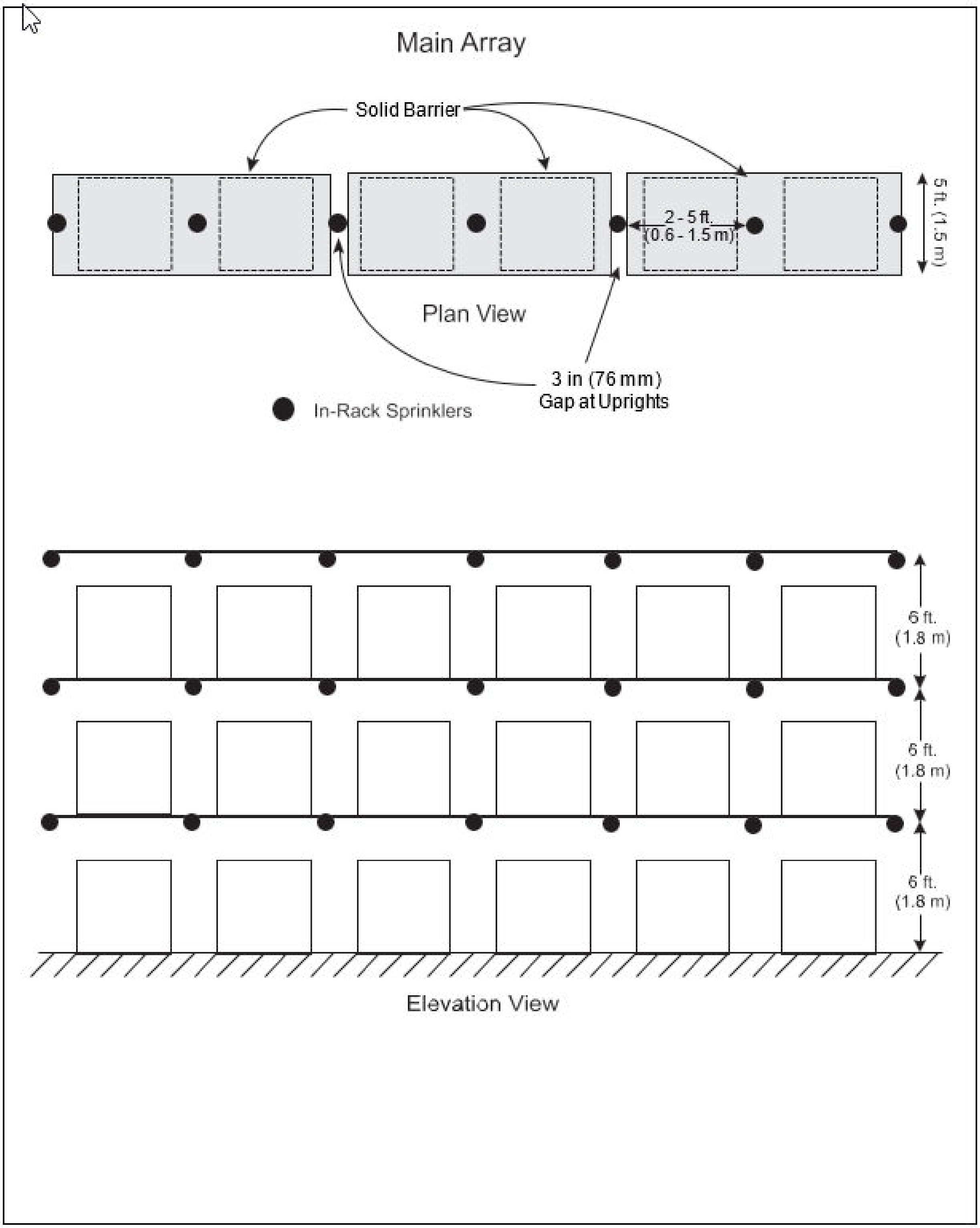

Figure 16.6.X.1(a) Single-Row Rack Sprinkler Layout for Design Scheme "G" – Sprinklers in the Center of Rack

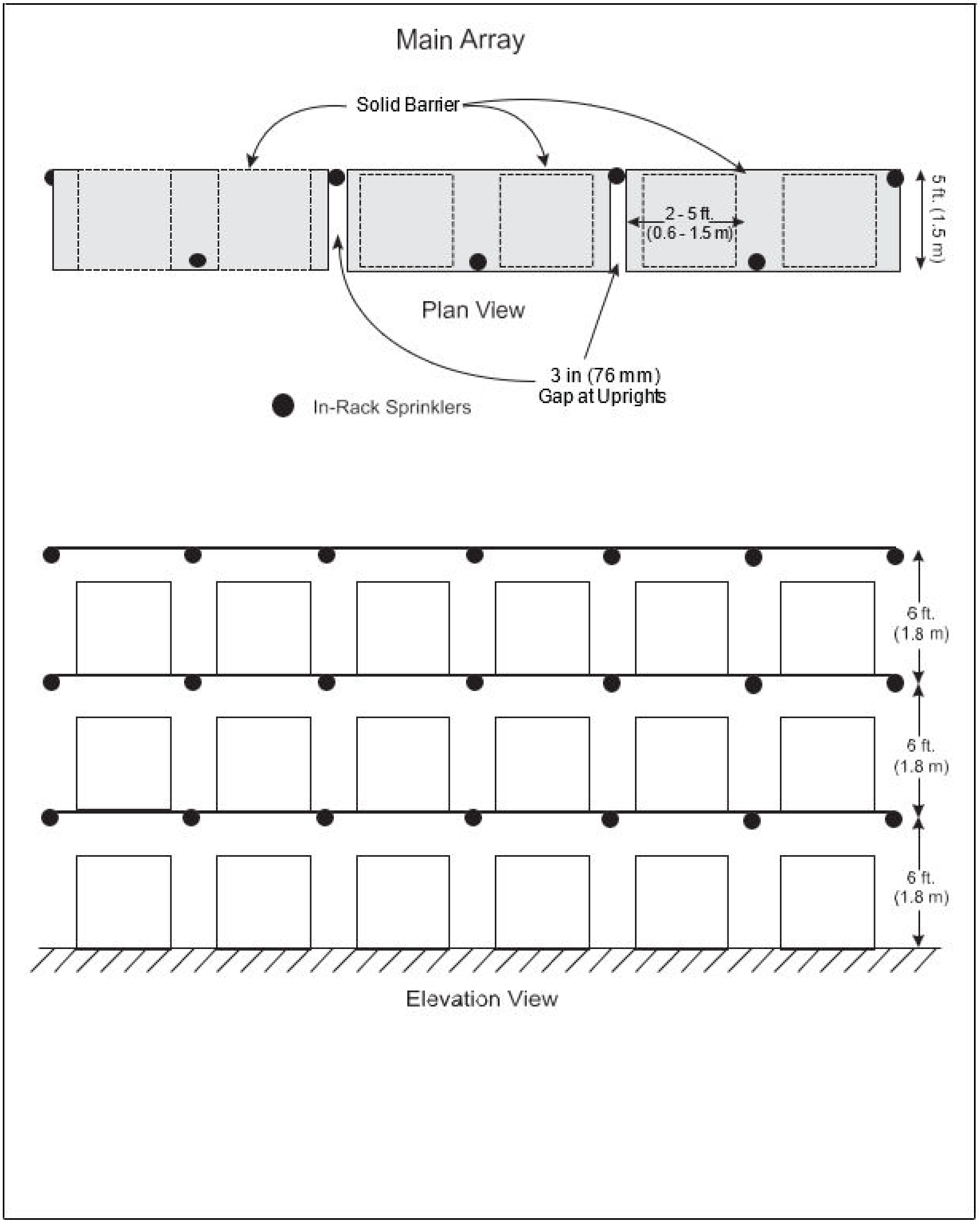

Figure 16.6.X.1(b) Single-Row Rack Sprinkler Layout for Design Scheme "G" – Sprinklers on Face of Rack

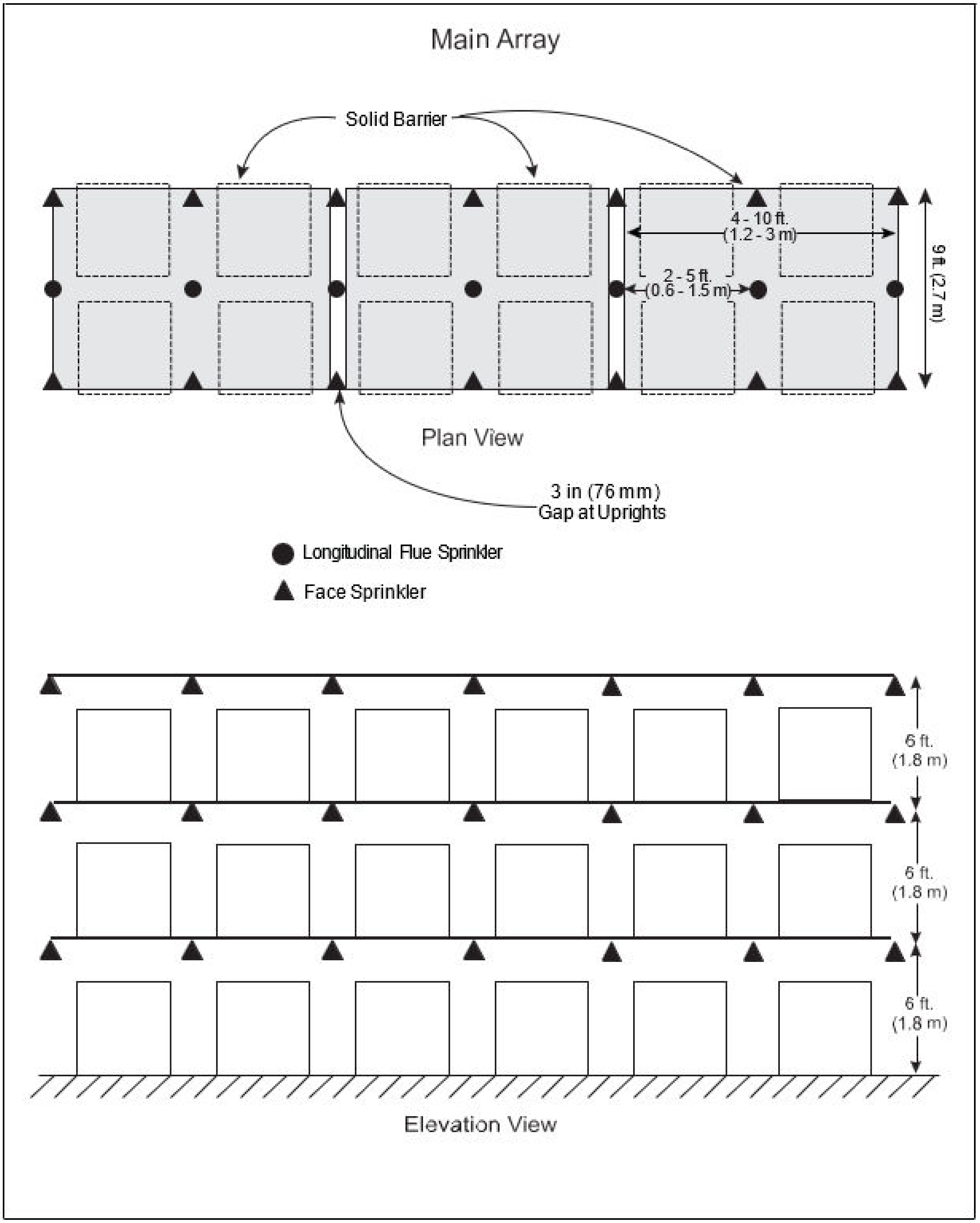

Figure 16.6.X.1(c) Double-Row Rack Sprinkler Layout for Design Scheme "G"

Proposed Addition to Table 16.5.3.14

Liquid Type/Flash Point	Container Capacity	Container Type	Packaging	Maximum Ceiling Height ft (m)	Maximum Storage Height ft (m)	Maximum Rack Depth ft (m)	Minimum Aisle Width ft (m)	Ceiling Sprinkler Protection					In-Rack Sprinkler Protection			
								Sprinkler Type		Design			Sprinkler Type		Design	
								K-factor $gpm/psi^{1/2}$ ($L/min/bar^{1/2}$)	Response/Nominal Temperature Rating/Orientation	Density gpm/ft^2 (mm/min)	Area ft^2 (m^2)	Number of Sprinklers @ Pressure psi (bar)	K-factor $gpm/psi^{1/2}$ ($L/min/bar^{1/2}$)	Response/Nominal Temperature Rating/Orientation	Minimum Discharge Flow gpm (L/min)	Layout
Class IB, Class IC, Class II, and Class IIIA Liquids [FP < 200°F (93°C) and BP ≥ 100°F (37.8°C)]	≤5 oz (150 ml)	Glass or Plastic	Cartoned	Unlimited	Unlimited	9 (2.7)	8 (2.4)	Fire Protection Design Scheme "G" (See 16.6.X) [New fire protection scheme]								