TECHNICAL REPORT FOR NFPA 30B

Fire Protection Scheme A for Cartoned Plastic Aerosol 3 Products and Level 2 and 3 Aerosol Products

FM Global®

Fire Protection Scheme A for Cartoned Plastic Aerosol 3 Products and Level 2 and 3 Aerosol Products

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For

NFPA 30B Code for the Manufacture and Storage of Aerosol Products

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Disclaimer

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1. Introduction

Plastic aerosol containers are a relatively new product in the marketplace that provide numerous commercial benefits, including: design and shape flexibility, low inventory costs, rust and BPA free. However, appropriate fire protection guidance for the product needed to be established. Protection for aerosol products is specified in FM Global's Property Loss Prevention Data Sheet 7-31, Storage of Aerosol Products [1] and also in NFPA 30B, Code for Manufacture and Storage of Aerosol Products [2]. Guidance in both documents was derived from a series of small-, intermediate-, and large-scale fire tests conducted in the late 1970s and early 1980s. All the protection guidance was based on tests with metal (steel or tinplate) containers and is specified based on content-bottle combinations. However, the plastic aerosol containers behave differently and the existing classification methods for metal aerosol products are not appropriate.

FM Global led a long-term project to properly understand the hazard of the product and to specify fire protection guidance for incorporation into Data Sheet 7-31 and NFPA 30B. FM Global partnered with the Plastic Aerosol Research Group (PARG), which is a consortium of commercial aerosol manufacturers. The member companies of the PARG contribute funding and resources to the organization, with an aligned interest in developing the plastic aerosol product technology. In cooperation with the PARG, FM Global developed a three-phase test program consisting of: Screening (single-can testing), Hazard Evaluation (12-pallet test), and Protection Determination (full-scale fire tests). Once the test program was developed, the PARG coordinated the production and donation of commodity for each phase of testing.

The first phase of the program was completed in 2011 and focused on understanding the failure mechanisms of plastic aerosol containers and identifying critical variables that impact the hazard level of the product. Variables identified included product heat of combustion, container size, pressure, product type, and fill method. The variables were assessed by conducting single-can tests and establishing a single-can index (SCI) for each set. The test uses a single can, placed in a holder, and suspended over a propane burner. The time to rupture and the energy released is measured to calculate an SCI. The SCI can be used to quantify the hazard of an individual aerosol container. This methodology was created for aerosol products with metal containers and the results obtained on the plastic aerosol products demonstrated that it was not useful in differentiating the hazard of this type of aerosol product.

An ancillary benefit of the 2011 testing was establishing combinations of variables that did not generate a high hazard product. These combinations included low heat of combustion (≤20% ethanol) and inert (i.e., nitrogen) propellants. Varieties of product combinations were assessed that could be protected based on existing guidance provided for non-pressurized commodities [3] [4] [5]. These combinations were submitted and incorporated into NFPA 30B as Plastic Aerosol 1 products [2] and considered equivalent to Class 3 commodity.

In 2016, the PARG was prepared to produce product for Phase 2 and Phase 3 of the original scope. Additional single-can tests were conducted on 19 product formulations, focusing on the ethanol percentage, propellant type, and pressure. Based on the test results, a final product was selected for large-scale fire testing. A high challenge aerosol formulation was selected that covered a wide variety of commercial products, representing the future market of plastic aerosol containers. The final individual plastic aerosol product was a 50/50 ethanol/water (v/v) mix pressurized with 10%, by weight, of a flammable hydrocarbon propellant in a 27 oz (800 mL) plastic bottle. For testing, bottles were stored in corrugated boxes and palletized.

The product for large-scale fire testing was produced in 2017 and prepared for shipment. In a parallel effort, a special permit [6] was issued for the shipment of plastic aerosol products for testing and disposal. Once these production and regulatory hurdles were cleared, the product was shipped to the FM Global Research Campus for testing. A decision tree (Appendix A) was created, incorporating both Phase 2 and Phase 3 objectives, and was agreed upon by all parties. A program was developed that would result in adequate protection for the product within three large-scale tests. The results of the testing are documented herein.

This report also contains an evaluation of the adequacy of using Fire Protection System Design Scheme A for the protection of Level 2 and 3 aerosol products. The PARG members wanted to determine if the storage of the new plastic aerosol product group could be stored with existing Level 2 and 3 aerosol products. The work done in this project showed that ceiling only protection would not work for the plastic aerosol product and NFPA 30B does not currently recognize the use of Fire Protection System Design Scheme A for Level 2 and 3 aerosol products. The intent is to incorporate the new plastic aerosol product information and the use of Fire Protection System Design Scheme A for Level 2 and 3 aerosol products into NFPA 30B.

2. FM Global Test Facilities Information

The tests for this program were conducted in the Large Burn Laboratory (LBL) located in the Fire Technology Laboratory at the FM Global Research Campus in West Glocester, Rhode Island. The LBL is a large-scale fire testing facility with spatial dimensions of 240 ft (73 m) long by 140 ft (43 m) wide and includes three separate test locations. The North movable ceiling and the South movable ceiling are both 80 ft x 80 ft (24.4 m x 24.4 m) test pads with adjustable-height, smooth, flat, horizontal ceilings. The ceilings are adjustable between 10 ft (3.0 m) and 60 ft (18.3 m). Between the two movable ceilings is the 35 ft (10.7 m) diameter, 20-MW Calorimeter, positioned 37 ft (11.3 m) above the floor. Figure 2.1-1 provides a plan-view illustration of the LBL.

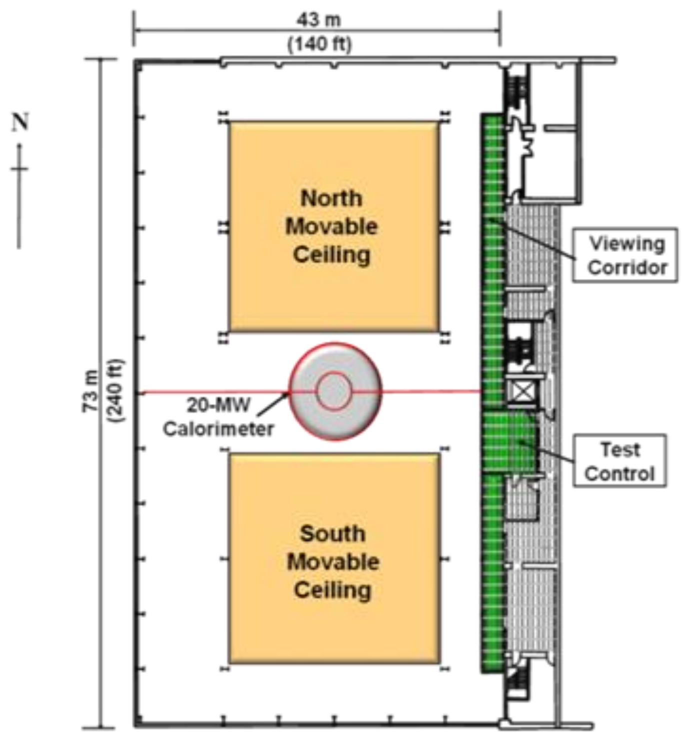


Figure 2.1-1: Illustration of FM Global Large Burn Laboratory test locations

The environment of the LBL is controlled to maintain a consistent temperature and humidity throughout the year. State-of-the art pumps, valves, and other process controls are provided in the laboratory to supply sprinkler water and fuels as required for individual test programs. The waste from testing is captured in a closed-loop system for onsite processing and reuse (water), or offsite recycling as needed. Smoke from testing is captured and processed by the air emission control system (AECS) with all exhaust ducts connecting to a wet electrostatic precipitator (WESP) prior to the cleaned gases venting to the atmosphere. Extraction points are present above each of the movable ceilings, as well as the calorimeter, which 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. All tests are conducted at an exhaust rate of 200,000 ft^3/min (94.4 m^3/s).

3. Cartoned Plastic Aerosol Product Fire Tests

3.1 Testing Overview

3.1.1 Test Summaries

Table 3-1: Plastic Aerosol 3 Commodity Fire Test Results

TEST SETUP	TEST NO	**001**	**002**	**003**
	DATE	08/07/2017	08/11/2017	09/06/2017
	PRIMARY TEST COMMODITY	Cartoned Plastic Aerosol Containers		
	MAIN ARRAY SIZE [pallets] TARGET ARRAY SIZE [pallets]	2 x 4 x 4 DRR (2) 1 x 4 x 4 SRR	2 x 8 x 3 DRR (2) 1 x 4 x 3 SRR	2 x 8 x 5 DRR (1) 2 x 4 x 5 DRR (1) 1 x 4 x 5 SRR
	CEILING HEIGHT [ft (m)]	30 (9.1)		
	STORAGE HEIGHT [ft (m)]	20 (6.1)	15 (4.6)	25 (7.6)
	AISLE WIDTH [ft (m)]	8 (2.4)		
	IGNITION LOCATION	Under 1, Offset		Under 1, Face
	CARTON MOISTURE CONTENT [% dry (wet)]	6.42 (6.86)	6.59 (7.05)	6.92 (7.44)
	RELATIVE HUMIDITY [%]	30	30	32
	AMBIENT TEMPERATURE [°F (°C)]	79 (26)	81 (27)	77 (25)
PROTECTION	CEILING K-FACTOR [gpm/psi$^{1/2}$ (L/min/bar$^{1/2}$)]	14.0 (200)		
	CEILING TEMP RATING [°F (°C)]	155 (68)		
	CEILING SPACING [ft x ft (m x m)]	10 x 10 (3.0 x 3.0)		
	CEILING DISCHARGE PRESSURE [psi (bar)]	75 (5.2)		50 (3.5)
	CEILING DESIGN DENSITY [gpm/ft² (mm/min)]	1.2 (49)		1.0 (41)
	HORIZONTAL BARRIER LOCATION [ft (m)]	N/A	N/A	10 (3.0) and 20 (6.1)
	IN-RACK K-FACTOR [gpm/psi$^{1/2}$ (L/min/bar$^{1/2}$)]			8.0 (160)
	IN-RACK TEMP RATING [°F (°C)]			155 (68)
	IN-RACK SPACING [ft (m)]			Scheme A
	IN-RACK PRESSURE [psi (bar)]			50 (3.5)
	IN-RACK FLOW RATE [gpm (L/min)]			57 (216)
TEST RESUTLS	FIRST CEILING SPRINKLER [min:sec]	0:42	0:49	2:09
	TOTAL CEILING OPERATIONS	11 UNACCEPTABLE	18 UNACCEPTABLE	2
	FIRST IN-RACK SPRINKLER [min:sec]	N/A	N/A	1:02
	TOTAL IN-RACK OPERATIONS			5 ACCEPTABLE
	PEAK 1-MIN AVG STEEL TEMP [°F (°C)]	128 (53) ACCEPTABLE	128 (50) ACCEPTABLE	135 (57) ACCEPTABLE
	EXTENT OF FIRE DAMAGE	UNACCEPTABLE	INCONCLUSIVE	ACCEPTABLE
	TEST DURATION [min:sec]	30:00	3:00	20:00

3.1.2 Test Materials

3.1.2.1 <u>Plastic Aerosol Product</u>

The primary commodity was plastic aerosols which was a generic representative of future commercially available products. An individual plastic aerosol container was comprised of a 50/50 ethanol/water (v/v) mix[1] pressurized with 10%, by weight, of a flammable hydrocarbon propellant in a 27 oz (800 mL) [2] plastic bottle. The average estimated heat of combustion of the product was 6,100 BTU/lb (14.1 kJ/g). The propellant pressurized the bottle to approximately 46 psi (3.2 bar) at standard temperature (70 °F [21 °C]). The propellant and the ethanol/water mix are immiscible and form two separate layers within the bottle, with the propellant on top. A small headspace (~15% of volume) was present at the top of the bottle.

Eight bottles were packaged in corrugated boxes, with corrugated dividers between each bottle. The carton dimensions were 12.75 in. x 6.5 in. x 10.81 in. tall (324 mm x 165 mm x 275 mm tall). A photo of an individual box is provided in Figure 3.1.2.1-1. The commodity was placed in four layers upon 42 in. x 42 in. (1067 mm x 1067 mm) slatted-deck hardwood pallets. A total of 72 cartons were stacked on the pallet and stretch wrapped in place. A photo of a full pallet load is provided in Figure 3.1.2.1-2.

Figure 3.1.2.1-1: Carton of aerosol containers with dividers.

Figure 3.1.2.1-2: Pallet load of cartoned aerosol product.

3.1.2.2 <u>Plastic Aerosol and Standard Commodity Mixed Pallets</u>

To broaden the array and provide a larger footprint to assess flame spread, mixed pallet commodity was used at the extents of the array. The mixed pallet commodity was comprised of 24 cartons of aerosol lining one face of the pallet, backed by four boxes of a standard FM Global commodity and stretch

[1] Ethanol/water mix between 31-50% is considered a Group 3 water-miscible liquid per FM Global Property Loss Prevention Data Sheet 7-29 [4].

[2] 34 oz (1 L) bottles were also considered for the program. The overall pallet loading was higher for 27 oz (800 mL) bottles so they were selected for the program as a worst-case condition for assessment.

wrapped in place. Either FM Global Standard Cartoned Unexpanded Plastic (CUP) commodity or FM Global Standard Class 3 commodity was used on a mixed pallet. A description of the CUP and Class 3 commodities is provided in Section 3.1.2.3 and Section 3.1.2.4, respectively. A photo of a mixed commodity pallet at the extent of an array is provided in Figure 3.1.2.2-1.

Figure 3.1.2.2-1: Mixed pallet commodity at extent of array.

Figure 3.1.2.3-1: FM Global Standard Cartoned Unexpanded Plastic (CUP) commodity.

3.1.2.3 FM Global Standard Cartoned Unexpanded Plastic Commodity

The FM Global Standard Cartoned Unexpanded Plastic commodity consists of rigid crystalline polystyrene cups (empty, 16 oz (0.46 L)) packaged, facing down, in a single-wall corrugated containerboard box. The cups are individually compartmentalized with single layer corrugated board partitions, arranged in five layers of 25 cups per layer, yielding a total of 125 cups per box. Each cup is separated by corrugated containerboard partitions, and each layer is separated by a corrugated containerboard pad. Eight 21 in. (53 cm) cubic cartons are set in a 2 x 2 x 2 arrangement on an ordinary, two-way, slatted deck, hardwood pallet resulting in a total dimension of 42 in. x 42 in. x 47 in. high (1.07 m x 1.07 m x 1.19 m high). Total combustible weight of one pallet load is approximately 162.8 lb (73.8 kg); the corrugated containerboard weighs approximately 43.7 lb (19.8 kg), the plastic cups weigh approximately 69.7 lb (31.6 kg), and the hardwood pallet that supports the commodity weighs approximately 49.4 lb (22.4 kg). A photo of the CUP commodity (pallet included) is provided in Figure 3.1.2.3-1. FM Global CUP commodity was used as both full pallets and mixed pallets within an array.

3.1.2.4 <u>FM Global Class 3 Commodity</u>

The FM Global Standard Class 3 test commodity consists of paper cups placed in a single-wall corrugated containerboard box. This commodity represents cellulosic materials stored in thin corrugated boxes. Five layers of 25 paper cups fill the cubic box, yielding a total of 125 cups per box. Each paper cup is separated by corrugated containerboard partitions, and each layer is separated by a corrugated containerboard pad. Eight 21 in. (53 cm) cubic cartons are set in a 2 x 2 x 2 arrangement on an ordinary, two-way, slatted deck, hardwood pallet, resulting in a total dimension of 42 in. x 42 in. x 47 in. high (1.07 m x 1.07 m x 1.19 m high). Total combustible weight of one pallet load is approximately 126.2 lb (57.2 kg); the corrugated containerboard weighs approximately 43.7 lb (19.8 kg), the paper cups[3] weigh approximately 33.1 lb (15 kg), and the hardwood pallet that supports the commodity weighs approximately 49.4 lb (22.4 kg). A photo of the Class 3 (pallet included) commodity is provided in Figure 3.1.2.4-1. The Class 3 commodity was only used in Test 3 in the mixed pallets.

Figure 3.1.2.4-1: FM Global standard Class 3 commodity.

3.1.3 Sprinkler Protection

For all tests, the ceiling-level sprinkler system was comprised of K-factor 14.0 gpm/psi$^{1/2}$ (200 lpm/bar$^{1/2}$) pendent, quick response, sprinklers with a 155^{o}F (68^{o}C) bulb. The sprinklers were installed on 10 ft x

[3] A single paper cup weighs about 0.5 oz (15 g).

10 ft (3.0 m x 3.0 m) spacing and with the thermal sensing element 13 in. (330 mm) from the ceiling. The selection of a K-factor 14.0 gpm/psi$^{1/2}$ (200 lpm/bar$^{1/2}$) was based on the wide use of the sprinkler for existing locations storing metal aerosol containers per NFPA 30B [2] and FM Global Data Sheet 7-31 [1]. Although no direct comparison is drawn between metal and plastic aerosol containers, future storage of plastic aerosol containers was anticipated to be in locations currently storing metal aerosol containers.

For Test 3, an in-rack protection scheme was used which was comprised of K-factor 8.0 gpm/psi$^{1/2}$ (160 lpm/bar$^{1/2}$) pendent, quick response, sprinklers with a 155°F (68°C) bulb. A description of the in-rack protection scheme and sprinkler spacing is provided in Section 3.1.8.

3.1.4 Documentation and Instrumentation

3.1.4.1 Documentation

Documentation for each test included video, still photography, and audio recordings of the visual observations made during the test. The video documentation included three high definition digital video cameras, an infrared (IR) camera, and a GoPro camera for qualitative assessments of the fire. The digital video cameras were placed around the test array to provide multiple views. The GoPro camera was placed at elevation to provide an overhead view of the test. The IR camera was placed alongside the southeast camera, which was considered the main camera.

3.1.4.2 Instrumentation

The following instrumentation was installed for tests conducted under the movable ceiling:

- Bare-bead, 0.8 mm (20 gauge), thermocouples installed 6.5 in. (165 mm) below the ceiling at numerous locations. The thermocouples had a response time corresponding to a Response Time Index (RTI) of 14.5 (ft-s)$^{1/2}$ (8 (m-s)$^{1/2}$).
- Thermocouples imbedded in a cross-shaped steel angle, made from two 4 ft (1.2 m) long pieces, attached at the ceiling center. Thermocouples are imbedded at the center, at 6 in. (150 mm), and at 12 in. (300 mm) from the ceiling center.
- Flow meters and pressure controllers to monitor and control the sprinkler system.
- Electrical circuits on each sprinkler to determine individual sprinkler activation times.
- Gas analyzers to measure the generation of carbon dioxide (CO_2), carbon monoxide (CO), total hydrocarbons (THC), and the depletion of oxygen (O_2) in the test space.

3.1.5 Test Evaluation Criteria

The following criteria were established for each test and descriptions indicate pass/fail thresholds.

3.1.5.1 Extent of Fire Damage

Fire damage should be confined within the outermost transverse flues of the main array and maintained within product comprised of cartoned plastic aerosols. Fire jump to the target arrays is permitted, provided the fire does not propagate beyond the cartoned plastic aerosols. Any fire spread observed into product comprised of FM Global standard commodity is considered unacceptable. The fire must not demonstrate any potential for further propagation at the time of test termination.

3.1.5.2 Sprinkler Operations

The allowable number of ceiling sprinkler operations was based on existing designs for metal aerosol containers specified in NFPA 30B [2] and FM Global Data Sheet 7-31 [1]. Although no direct comparison is drawn between metal and plastic aerosol containers, future storage of plastic aerosol containers was anticipated to be in locations currently storing metal aerosol containers. Therefore, determining if existing protection was adequate was a primary concern.

Most ceiling-only sprinkler protection options within NFPA 30B and Data Sheet 7-31 are provided as a number of sprinklers at a design pressure. The K-factor and design pressure are based on the storage method, the hazard level of the aerosol, and on whether the product is cartoned or uncartoned. However, nearly all the protection options specify a 12-sprinkler design for quick response sprinklers. Applying a 50% safety factor, to account for conditions not represented during fire testing, the number of allowable sprinkler operations in any test was set to 8. Additionally, sprinklers along the perimeter of the test ceiling are not allowed to operate. Sprinklers operating at the ceiling perimeter indicate that high temperature gases made it to the edge of the ceiling and could have traveled further along the ceiling, operating additional sprinklers, had they been present.

The operation of a sprinkler is verified by a timing wire installed onto the sprinkler frame, creating a circuit that is monitored. Upon operation of the sprinkler, the circuit is broken and the event is monitored via electrical signal. In addition, a post-test ceiling checkout verifies the location of all operated sprinklers and is compared to events registered by the data acquisition system.

3.1.5.3 Steel Temperature

The maximum allowable ceiling steel temperature is 1000°F (538°C). This is based on the assessment that structural steel loses 50 percent of its load bearing strength upon reaching the 1000°F (538°C) threshold. The loss of strength could cause failure of the ceiling structure resulting in collapse of the roof. Ceiling temperatures exceeding this threshold during a test are an indication of ineffective fire protection.

3.2 Test 1

The first test of the program was conducted with a limited footprint of cartoned plastic aerosols. By limiting the footprint, the overall hazard of the stored product was reduced, while still providing a sufficient quantity of fuel to indicate the likelihood of a successful protection scheme. The primary assessment was the type of fire resulting from ruptured aerosol containers and the ability of ceiling-only sprinklers to control the fire. To meet the extent of fire damage criterion, the fire would have to be contained within the ignition flue. If all other criteria were acceptable, but fire traveled outside of the aerosol product, the test would be repeated with a larger footprint array. If other evaluation criteria were not met, subsequent tests would be modified to provide the best chance for success.

3.2.1 Test 1 Setup

The fire was a large-scale rack storage arrangement with two target arrays. The main array was a double-row, open frame rack, that was 4 pallet-loads wide and 4 pallet-loads high. Each tier was separated by 5 ft (1.5 m), providing a nominal storage height of 20 ft (6.1 m). The actual product provided a storage height of 19 ft (5.8 m). The main array was comprised of cartoned plastic aerosols and FM Global standard CUP commodity. The inner 2x2 pallet core was comprised of cartoned plastic aerosols. The outer pallets of the array were CUP commodity. The two target arrays were single-row, open frame racks, that were 4 pallet-loads wide and 4 pallet-loads high. The target arrays were comprised entirely of CUP commodity. Target arrays were aligned parallel to the main array across an 8 ft (2.4 m) aisle. Both the longitudinal and transverse flues were nominal 6 in. (152 mm) spacing between the pallets. Plan and elevation view schematics of the test array are provided in Figure 3.2.1-1 and Figure 3.2.1-2, respectively. Photos of the test array are provided in Figure 3.2.1-3.

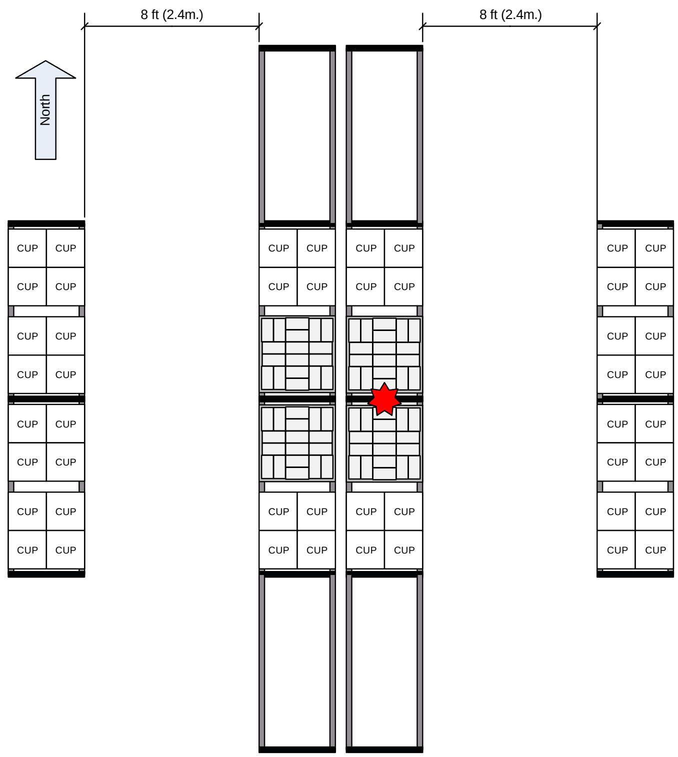


Figure 3.2.1-1: Plan view schematic – Test 1.

Ceiling-only sprinkler protection was provided by K-factor 14.0 gpm/psi$^{1/2}$ (200 lpm/bar$^{1/2}$) pendent QR sprinklers with a 155^{o}F (68^{o}C) bulb, as described in Section 3.1.3. The sprinklers were installed on 10 ft x 10 ft (3.0 m x 3.0 m) spacing. The system discharge pressure of 75 psi (5.2 bar) resulted in a flow of 120 gpm (454 lpm) per sprinkler, and a 1.2 gpm/ft^2 (49 mm/min) density at the floor. The ceiling height was set to 30 ft (9.1 m) for this test. Ignition was achieved with two standard half igniters[4] positioned under 1 sprinkler, offset within the rack, 2 ft (0.6 m) from the center line of the longitudinal flue, closest to the east face of the main array. The overhead sprinkler was aligned directly over the intersection of the transverse and longitudinal flues.

[4] Each half igniter is a 3 in. x 3 in. (76 mm x 76 mm) cylinder of rolled cellucotton. Each igniter is soaked in 4 oz (118 ml) of gasoline and sealed in a plastic bag.

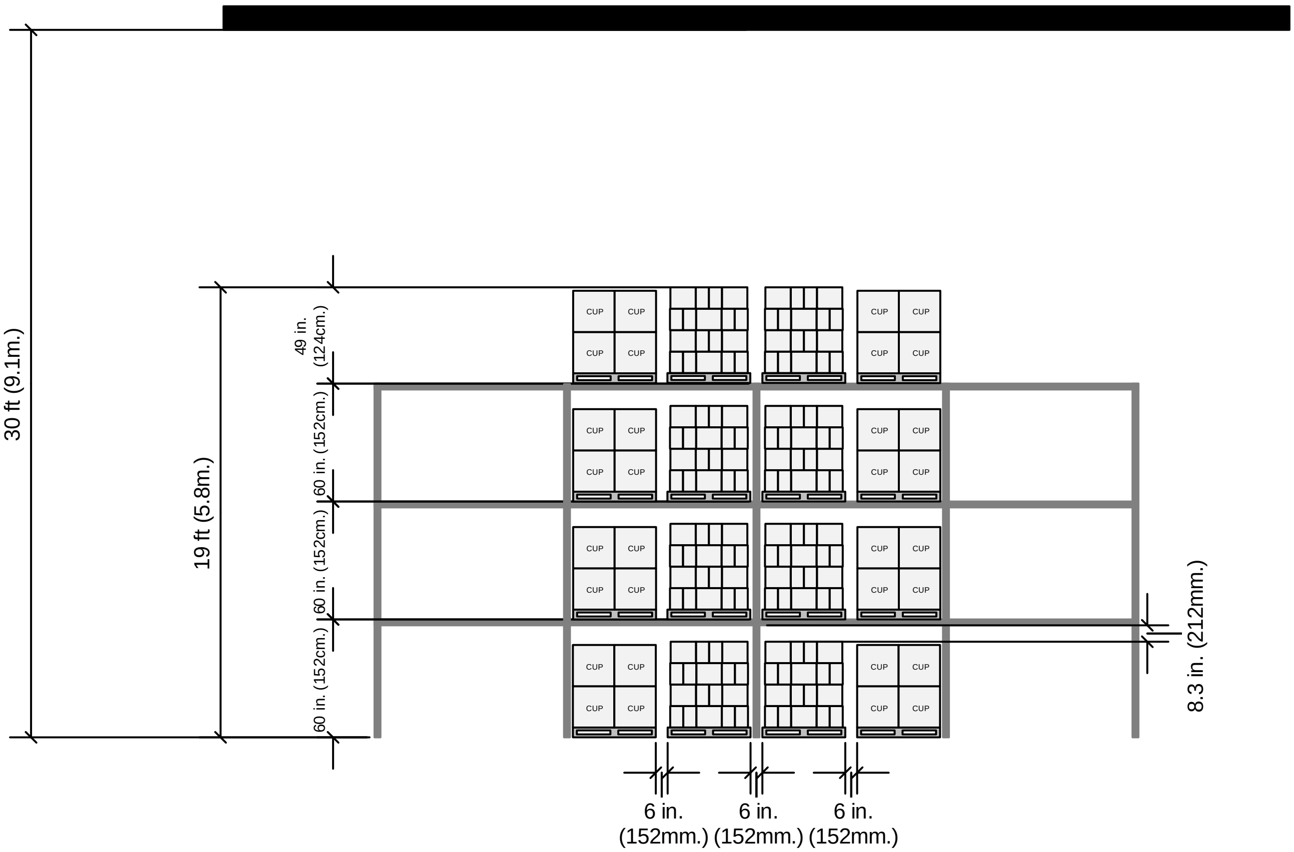


Figure 3.2.1-2: Elevation view schematic of the main array – Test 1.

Figure 3.2.1-3: Pre-test photos of array – Test 1[5].

[5] A chain-link fence was provided on one corner of the array to protect on-site fire fighters from rocketing aerosol containers.

3.2.2 Test 1 Results

Upon ignition, flames traveled up the transverse flue and reached the top of the first tier at 20 s. Flames began to enter the second tier at 33 s and the first rupture was observed at 36 s (Figure 3.2.2-1). After several ruptures, the first sprinkler operated at 42 s (Figure 3.2.2-2). The fire continued to burn within the main array and the rate of aerosol ruptures increased to several per second. Each individual rupture created a large fire ball that extended to ceiling level (Figure 3.2.2-3 and Figure 3.2.2-4). At 1 min 9 s, seven sprinklers operated simultaneously and at 1 min 19 s, a total of nine sprinklers had operated. Throughout the remainder of the test the rate of aerosol ruptures decreased and eventually ceased altogether by approximately 21 min into the test. CUP commodity at the extent of the main array was involved at 30 min when the test was terminated. A total of 11 sprinklers operated during the test.

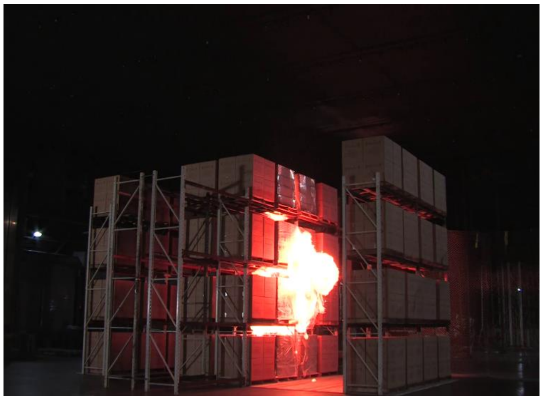


Figure 3.2.2-1: Photo of first rupture – Test 1 (36 s).

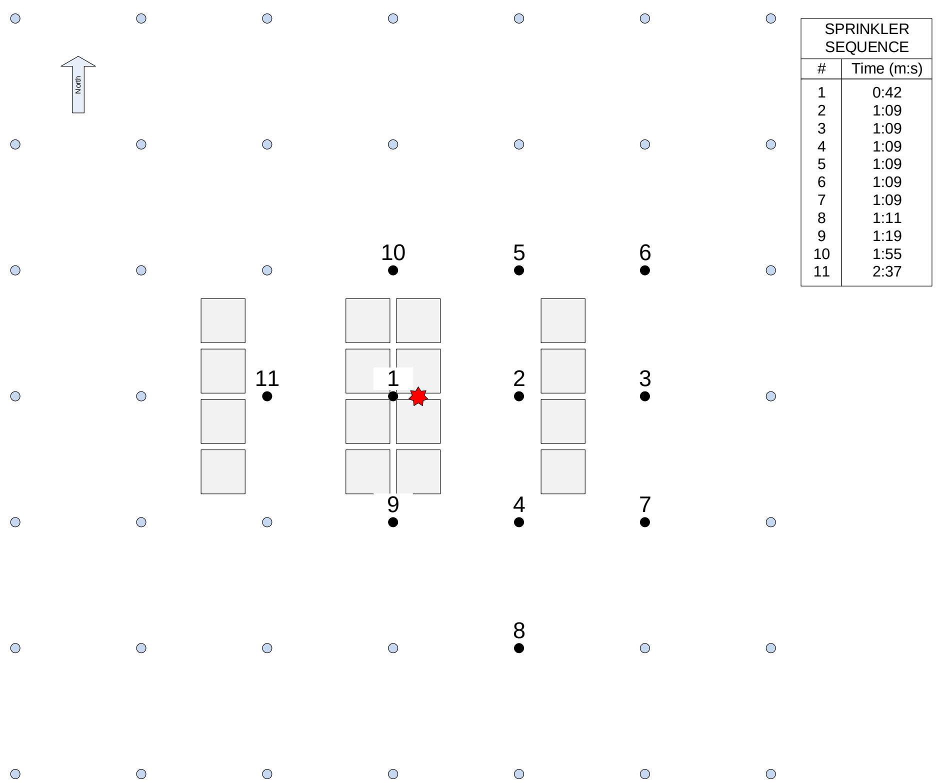
Figure 3.2.2-2: Photo of first sprinkler operation – Test 1 (42 s).

Figure 3.2.2-3: Photo of fire ball from aerosol rupture – Test 1 (1 min 7 s).

Figure 3.2.2-4: Photo of fire balls reaching ceiling level – Test 1 (1 min 10 s).

Based on the evaluation criteria, the ceiling protection provided was unsuccessful in controlling the fire. The 11 sprinklers that operated exceeded the evaluation criterion of 8 sprinklers. The fire also spread into the CUP commodity, yielding an inconclusive result for acceptable control of fire spread. The peak observed ceiling steel temperature was 128°F (53°C), which was within acceptable limits. A photo of the post-test array is provided in Figure 3.2.2-5. The sprinkler operation pattern is shown in Figure 3.2.2-6. Data plots from the test can be found in Appendix B.

Figure 3.2.2-5: Post-test photo of array – Test 1.



SPRINKLER SEQUENCE	
#	Time (m:s)
1	0:42
2	1:09
3	1:09
4	1:09
5	1:09
6	1:09
7	1:09
8	1:11
9	1:19
10	1:55
11	2:37

Figure 3.2.2-6: Sprinkler operation pattern – Test 1.

3.3 Test 2

K-factor 14.0 gpm/psi$^{1/2}$ (200 lpm/bar$^{1/2}$) sprinklers operating at 75 psi (5.2 bar) were unsuccessful in protecting 20 ft (6.1 m) storage of cartoned plastic aerosols beneath a 30 ft (9.1 m) ceiling in Test 1. To improve the likelihood of success, several changes could have been made to the test setup; reduce storage height, reduce ceiling height, or increase sprinkler design density. For Test 2, the array storage height was reduced and the ceiling height and sprinkler design density were kept the same as in Test 1. In addition, a full footprint of plastic aerosol commodity was used to reduce the likelihood of unacceptable fire spread through the array.

3.3.1 Test 2 Setup

The fire was a large-scale rack storage arrangement with two target arrays. The main array was a double-row, open frame rack, 8 pallet-loads wide and 3 pallet-loads high. Each tier was separated by 5 ft (1.5 m), providing a nominal storage height of 15 ft (4.6 m). The actual product provided a storage height of 14 ft (4.3 m). The main array was comprised of cartoned plastic aerosols and aerosol-lined CUP commodity. The inner 2x6 pallet core was comprised of cartoned plastic aerosols. The outer pallets of the array were aerosol-lined CUP commodity. The two target arrays were single-row, open frame racks, 4 pallet-loads wide and 3 pallet-loads high. The target arrays were comprised of aerosol-lined CUP commodity. Target arrays were aligned east and west of the main array, parallel to the main array across an 8 ft (2.4 m) aisle. Both the longitudinal and transverse flues were nominal 6 in. (152 mm) spacing between the pallets. Plan and elevation view schematics of the test array are shown in Figure 3.3.1-1 and Figure 3.3.1-2, respectively. A photo of the test array is in Figure 3.3.1-3.

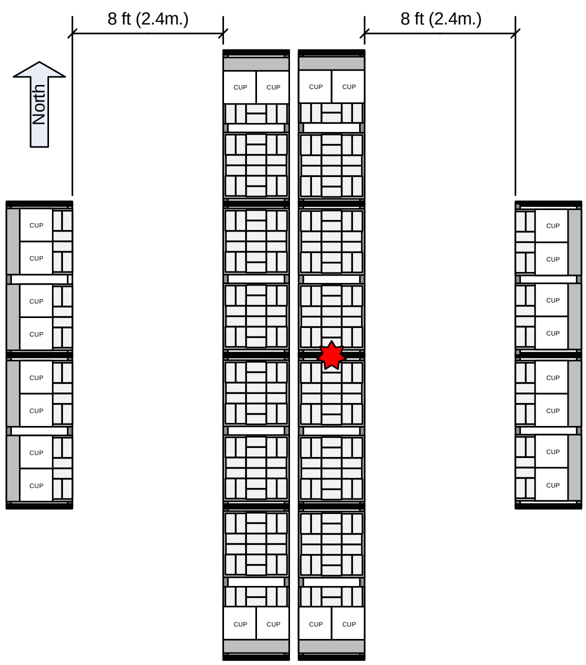


Figure 3.3.1-1: Plan view schematic – Test 2.

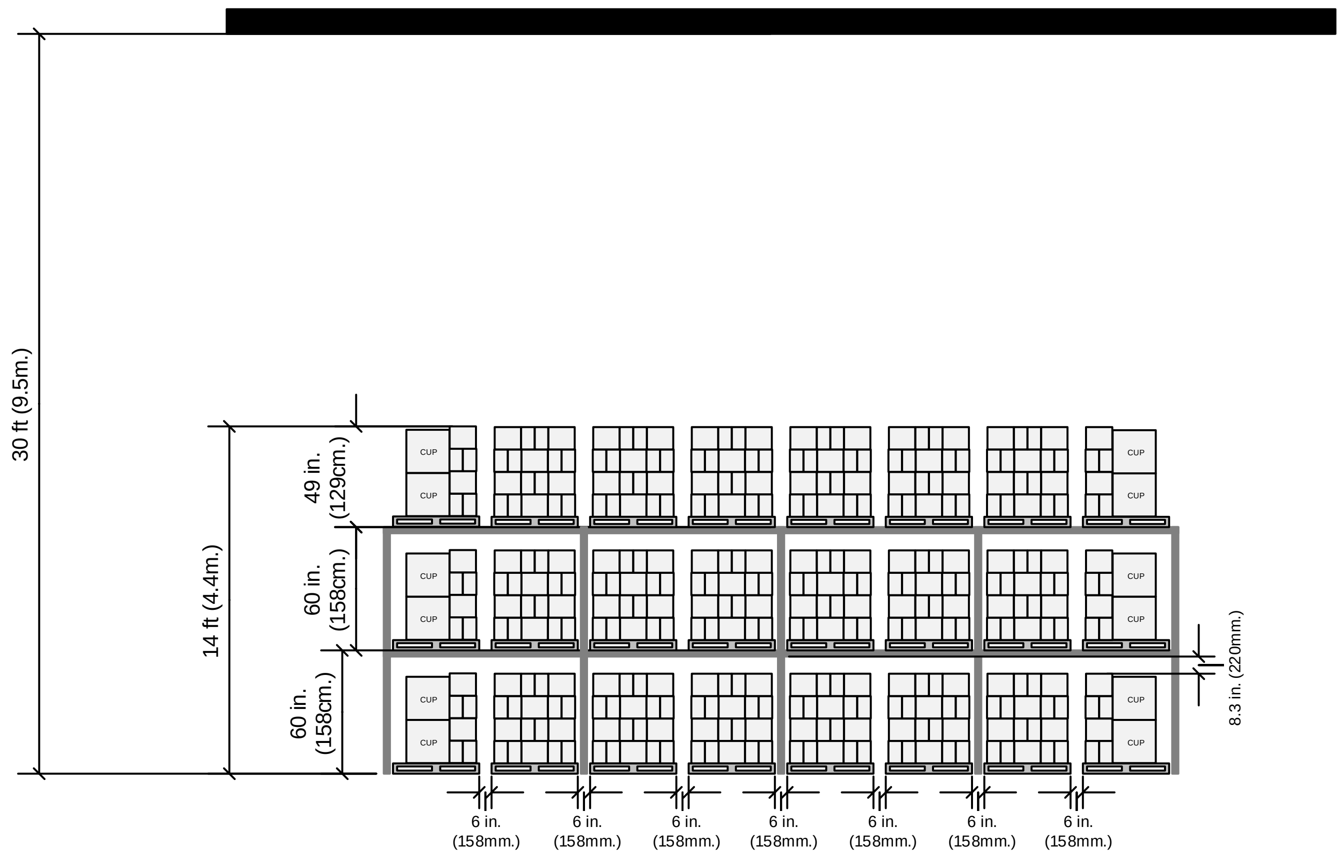


Figure 3.3.1-2: Elevation view schematic of the main array – Test 2.

Figure 3.3.1-3: Pre-test photo of array – Test 2.

Ceiling-only sprinkler protection was provided by K-factor 14.0 gpm/psi$^{1/2}$ (200 lpm/bar$^{1/2}$) pendent QR sprinklers with a 155°F (68°C) bulb, as described in Section 3.1.3. The sprinklers were installed on 10 ft x 10 ft (3.0 m x 3.0 m) spacing. The system discharge pressure of 75 psi (5.2 bar) resulted in a flow of

120 gpm (454 lpm) per sprinkler, and a 1.2 gpm/ft² (49 mm/min) density at the floor. The ceiling height was set to 30 ft (9.1 m) for this test.

Ignition was achieved with two standard half igniters[6] positioned under 1 sprinkler, offset within the rack, 2 ft (0.6 m) from the center line of the longitudinal flue, closest to the east face of the main array. The overhead sprinkler was aligned directly over the intersection of the transverse and longitudinal flues.

3.3.2 Test 2 Results

Upon ignition, flames traveled up the transverse flue and reached the top of the first tier at 22 s. The first plastic aerosol container ruptured at 37 s with several subsequent ruptures observed. The first sprinkler operation was at 49 s (Figure 3.3.2-1) and a second sprinkler operated at 1 min 5 s. Burning in the second-tier commodity caused a near-continuous series of aerosol ruptures with flames reaching ceiling level (Figure 3.3.2-2). This caused the simultaneous operation of 10 sprinklers, including five on the ceiling perimeter. The first 12 sprinkler operations were towards the east side of the ceiling. As the fire progressed, it exited the west side of the array where ceiling sprinklers had not yet operated. Another series of ruptures caused six additional sprinklers to operate between 2 min 23 s and 2 min 44 s. The test was terminated at 3 min.

Figure 3.3.2-1: Photo of first sprinkler operation – Test 2 (49 s).

Based on the evaluation criteria, the ceiling protection provided was unsuccessful in controlling the fire. At the time of test termination, 18 sprinklers had operated, including six perimeter operations. Both the number and location of sprinkler operations failed the evaluation criteria. The fire spread was maintained within the main array, but there was no evidence of control at the time of termination. The peak observed ceiling steel temperature was 128 °F (50 °C), which was within acceptable limits.

[6] Each half igniter is a 3 in. x 3 in. (76 mm x 76 mm) cylinder of rolled cellucotton. Each igniter is soaked in 4 oz (118 ml) of gasoline and sealed in a plastic bag.

Figure 3.3.2-2: Photo of product involvement – Test 2 (1 min 23 s).

A photo of the post-test array is provided in Figure 3.3.2-3. The sprinkler operation pattern is given in Figure 3.3.2-4. Data plots from the test are available in Appendix B.

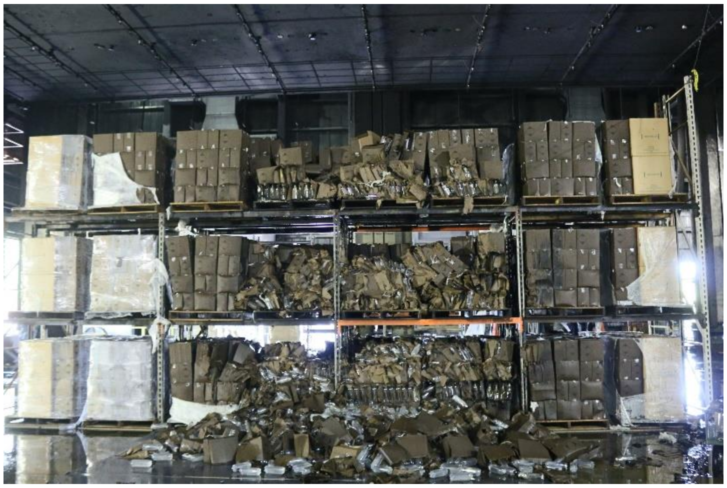
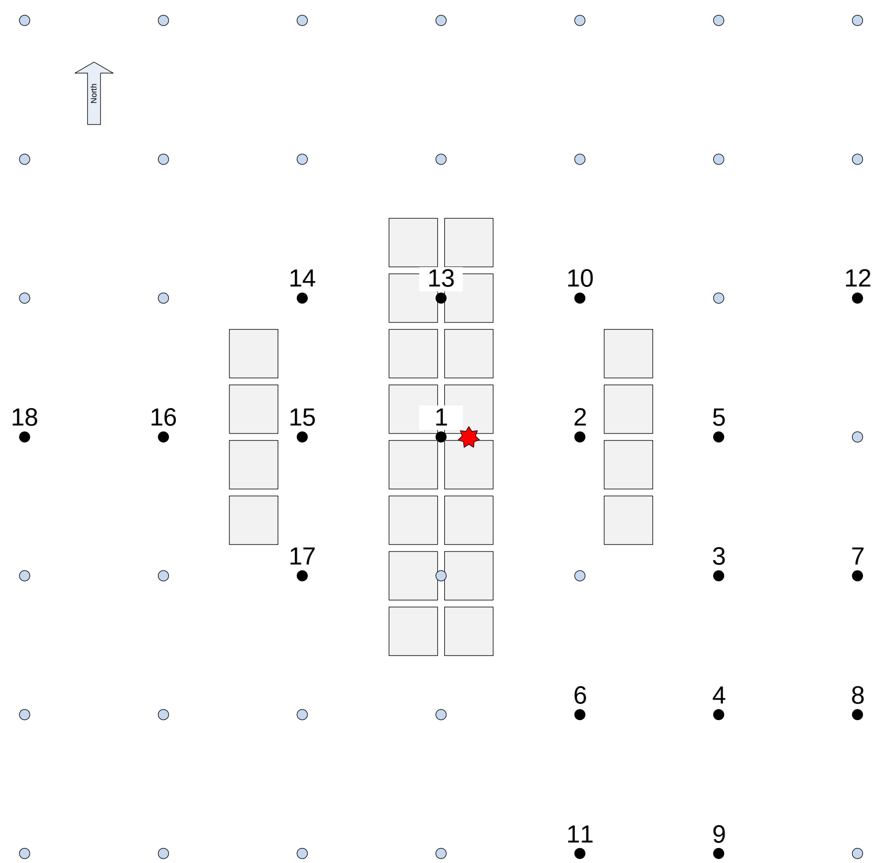


Figure 3.3.2-3: Post-test photo of array – Test 2 (target array removed).

3.4 Test 3

The results from Test 1 and Test 2 demonstrated that ceiling only protection using K-factor 14.0 gpm/psi$^{1/2}$ (200 lpm/bar$^{1/2}$) sprinklers operating at 75 psi (5.2 bar) was not sufficient to control the fire. The primary mode of failure in both tests was excessive ceiling sprinkler operations compared to existing protection options for metal aerosol containers [1] [2]. To meet the objective of determining protection guidance within three tests, a high level of protection was selected for the final test to ensure a high likelihood for success. No additional attempts were made to determine ceiling-only protection, though large K-factor sprinklers and/or higher sprinkler flow rates may be effective for the hazard.



SPRINKLER SEQUENCE	
#	Time (m:s)
1	0:49
2	1:05
3	1:22
4	1:23
5	1:23
6	1:23
7	1:23
8	1:23
9	1:24
10	1:24
11	1:24
12	1:25
13	2:23
14	2:24
15	2:42
16	2:42
17	2:43
18	2:44

Figure 3.3.2-4: Sprinkler operation pattern – Test 2.

For the third test, a combination of ceiling sprinklers, in-rack sprinklers, and horizontal barriers was tested to establish an acceptable protection scheme for the hazard of cartoned plastic aerosol containers. This protection level is referred to as Fire Protection Scheme A in FM Global Data Sheet 7-31 [1].

3.4.1 Test 3 Setup

The fire was a large-scale rack storage arrangement with two target arrays. The main array was a double-row, open frame rack, 8 pallet-loads wide and 5 pallet-loads high. Each tier was separated by 5 ft (1.5 m), providing a nominal overall storage height of 25 ft (7.6 m). The actual product provided a storage height of 24 ft (7.3 m). The main array was comprised of cartoned plastic aerosols, aerosol-lined Class 3 commodity, and CUP commodity. The inner 2x6x4-high pallet core was comprised of cartoned plastic aerosols. The outer pallets of the array were aerosol-lined Class 3 commodity. The entire top tier of the main array was comprised of CUP commodity.

The east target array was a double-row, open frame rack, 6 pallet-loads wide and 5 pallet-loads high. The west row of the target array, facing the main array was comprised of cartoned plastic aerosols in the first four tiers. The east row of the target array, facing away from the main array was comprised of aerosol-lined Class 3 commodity. The entire top tier of the target array was comprised of CUP commodity.

The west target array was a single-row, open frame rack, 4 pallet-loads wide and 5 pallet-loads high. The target array was comprised of aerosol-lined Class 3 commodity and CUP commodity. The first four tiers of the west target array were aerosol-lined Class 3 commodity. The entire top tier of the west target array was CUP commodity. Both target arrays were aligned parallel to the main array across an 8 ft (2.4 m) aisle. Both the longitudinal and transverse flues in all arrays were nominal 6 in. (152 mm) spacing between the pallets.

Fire Protection System Design Scheme A in-rack sprinkler protection was installed in both the main and east target array. At the 10 ft (3.0 m) and 20 ft (6.1 m) level, above the second and fourth tiers, respectively, a combination of horizontal barriers and in-rack sprinklers were installed. The horizontal barriers were ½" (13 mm) plywood placed between the rack uprights, covering both rows of the array and the longitudinal flue. The space created by the rack uprights was not covered by the barrier. Beneath the barrier were in-rack pipes and sprinklers running down the center longitudinal flue and the east and west face of the array. The longitudinal flue pipe had sprinklers installed on nominal 4 ft (1.2 m) spacing. The face pipes had sprinklers installed on nominal 8 ft (2.4 m) spacing at the rack uprights. The sprinklers were approximately 6 in. (152 mm) above the top of the commodity and 6 in. (152 mm) below the barrier. The face sprinklers were installed nominally 12 in. (305 mm) from the face of the pallets. All in-rack sprinklers were K-factor 8.0 gpm/psi$^{1/2}$ (160 lpm/bar$^{1/2}$) pendent QR sprinklers with a 155°F (68°C) bulb, as described in Section 3.1.3. The in-rack sprinkler design pressure was 50 psi (3.5 bar), resulting in a flow of 57 gpm (216 lpm) per sprinkler.

Ceiling-only sprinkler protection was provided by K-factor 14.0 gpm/psi$^{1/2}$ (200 lpm/bar$^{1/2}$) pendent QR sprinklers with a 155°F (68°C) bulb, as described in Section 3.1.3. The sprinklers were installed on 10 ft x 10 ft (3.0 m x 3.0 m) spacing. The system discharge pressure of 50 psi (3.5 bar) resulted in a flow of 100 gpm (379 lpm) per sprinkler, and a 1.0 gpm/ft^2 (41 mm/min) density at the floor. The ceiling height was set to 30 ft (9.1 m) for this test.

Ignition was achieved with one standard full igniter[7]. The ignition was under 1 sprinkler, located on the east face of the main array at the center of the pallet south of the center rack upright. The igniter was approximately 4 ft (1.2 m) east and 2 ft (0.6 m) south of the ceiling center. The overhead sprinkler was aligned directly over the intersection of the transverse and longitudinal flues at the ceiling center.

A plan view schematic of the test array is provided in Figure 3.4.1-1. An elevation view of the main array and a side elevation view of the entire array are presented in Figure 3.4.1-2 and Figure 3.4.1-3, respectively. Photos of the test array are shown in Figure 3.4.1-4. Photos of the in-rack sprinkler placement are shown in Figure 3.4.1-5.

[7] A full igniter is a 3 in. x 6 in. (76 mm x 152 mm) cylinder of rolled cellucotton. The igniter is soaked in 8 oz (240 ml) of gasoline and sealed in a plastic bag.

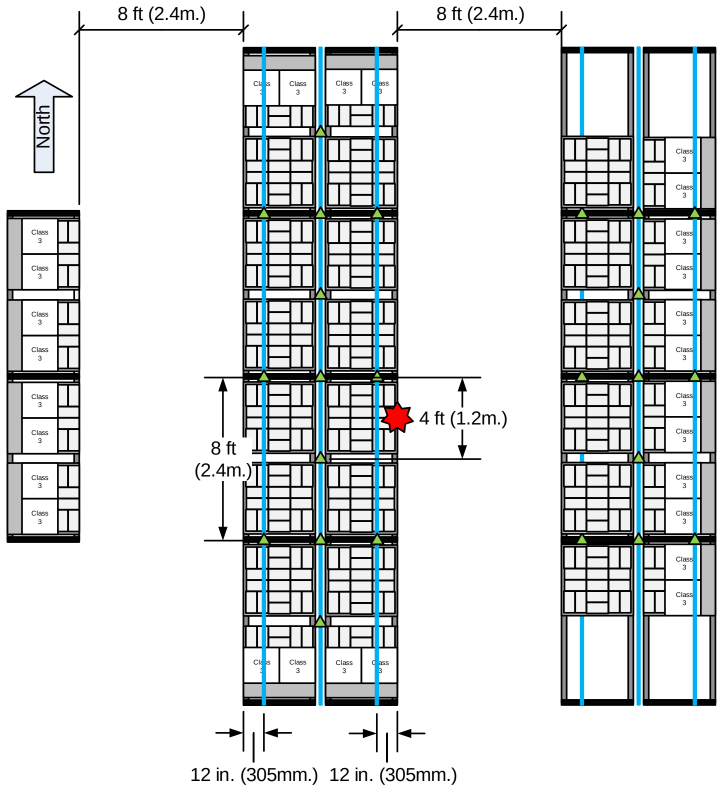


Figure 3.4.1-1: Plan view schematic of the test array – Test 3 (top layer of CUP not indicated).
Note: Green triangles indicate IRAS location.

3.4.2 Test 3 Results

Upon ignition, flames traveled up the east face of the main array. Flames reached the top of the first tier at 20 s. The flames started to extend up into the bottom of the second tier at 30 s, and the first aerosol container rupture was at 37 s (Figure 3.4.2-1). Ruptures from the aerosol containers were occurring on the east face of the main array and the fireballs extended across the 8 ft (2.4 m) aisle. The first two in-rack sprinkler operations occurred simultaneously below the 10 ft (3.0 m) barrier in the target array at 1 min 2 s (Figure 3.4.2-2). The fire continued to burn on the east face of the main array causing additional ruptures. A series of ruptures created a very large fireball (Figure 3.4.2-3) that caused the operation of two ceiling level sprinklers at 2 min 9 s (Figure 3.4.2-4). Three additional in-rack sprinklers operated between 2 min 14 s and 2 min 17 s. Two of the operations were below the 20 ft (6.1 m) barrier in the target array and the final in-rack operation was below the 10 ft (3.0 m) barrier in the main array. The fire was brought quickly under control with no additional aerosol ruptures observed after 5 min 15 s. A photo of the array, with no evidence of fire burning at 10 min, is provided in Figure 3.4.2-5. The test was terminated at 20 min.

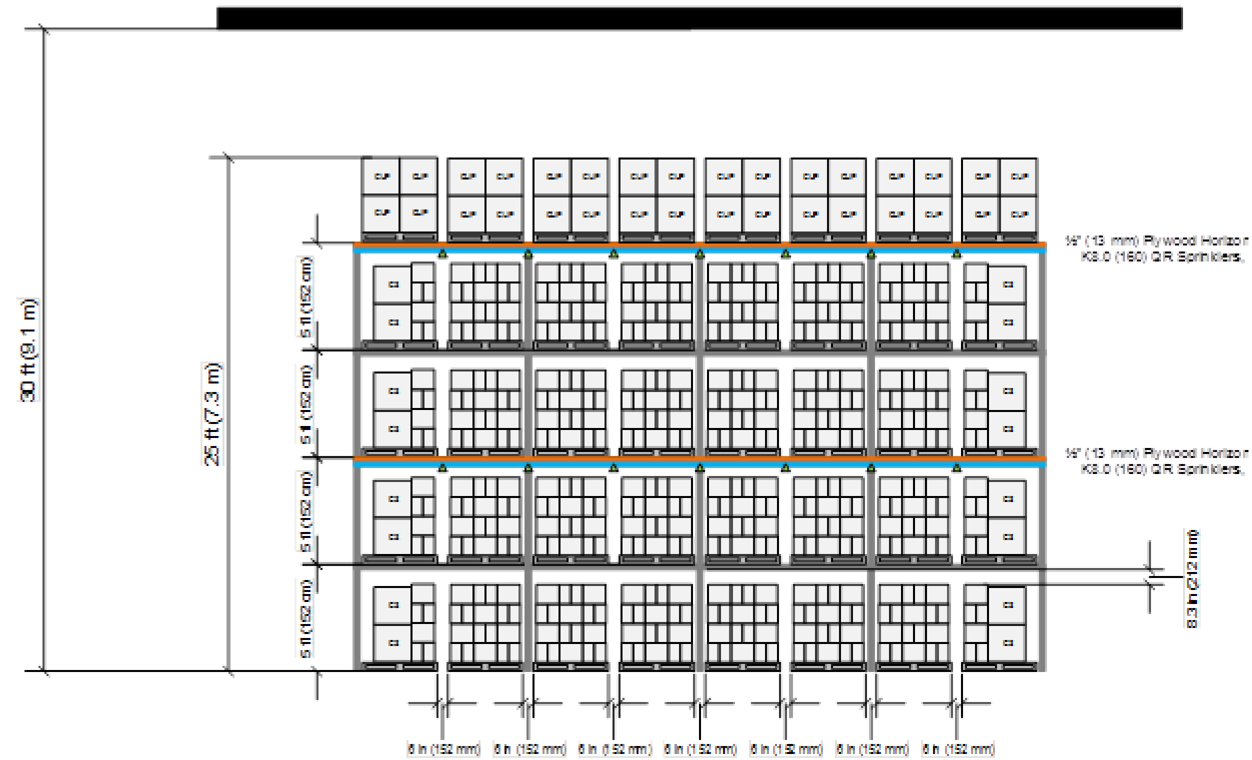


Figure 3.4.1-2: Elevation view schematic of main array – Test 3. Green triangles indicate IRAS location.

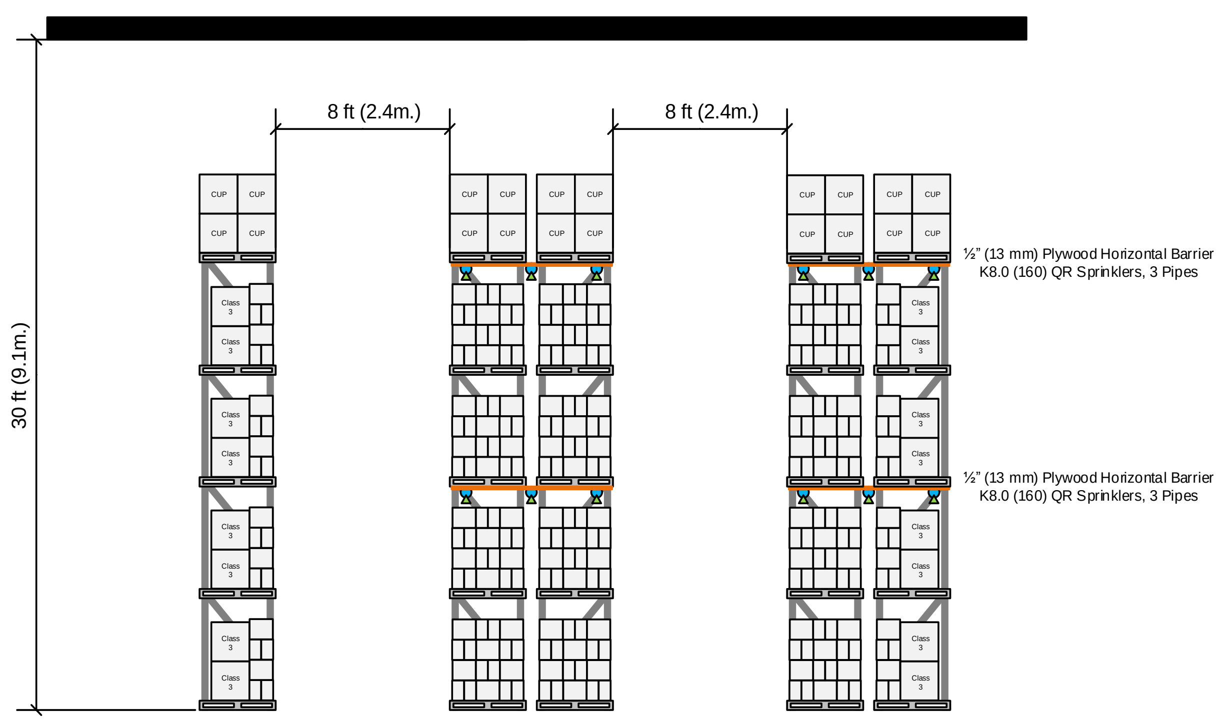


Figure 3.4.1-3: Side elevation view schematic of the test array – Test 3.

Figure 3.4.1-4: Pre-test photos of main array – Test 3.

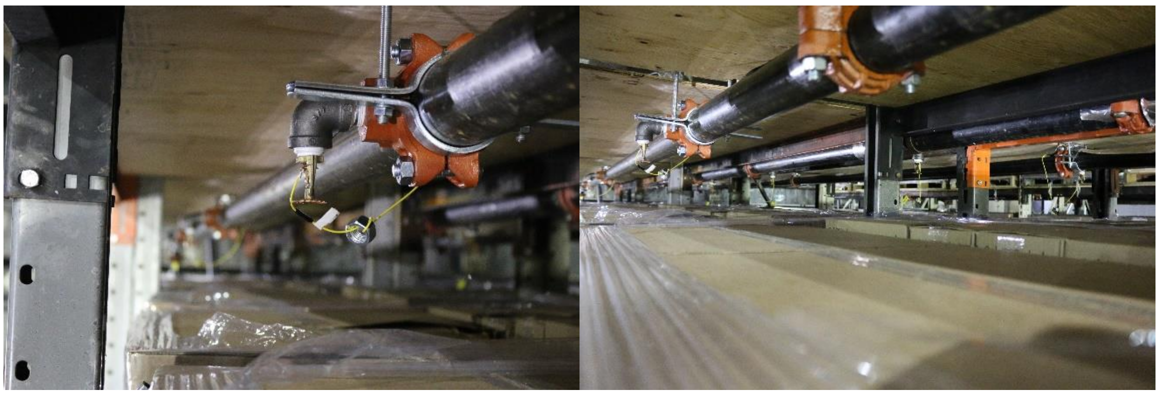


Figure 3.4.1-5: Photos of in-rack sprinkler placement – Test 3.

Based on the evaluation criteria, the combination of Scheme A fire protection and ceiling sprinkler protection was successful in controlling the rack storage fire of cartoned plastic aerosols. During the test, five in-rack sprinklers and two ceiling sprinklers operated. In-rack sprinklers operated at both the 10 ft (3.0 m) and 20 ft (6.1 m) level and operations occurred in both the main and target array. Fire spread was contained to the first two tiers of the main array and had limited horizontal flame reach (Figure 3.4.2-6). The peak observed ceiling steel temperature was 90°F (32°C), which was within acceptable limits. The in-rack sprinkler and ceiling sprinkler operation patterns are provided in Figure 3.4.2-7 and Figure 3.4.2-8, respectively. Data plots from the test are given in Appendix B.

Figure 3.4.2-1: Photo of first aerosol rupture – Test 3 (37 s).

Figure 3.4.2-2: Photo of first in-rack operation – Test 3 (1 min 2 s).

Figure 3.4.2-3: Photo of fire balls generated from plastic aerosol ruptures – Test 3 (2 min 5 s).

Figure 3.4.2-4: Photo of first ceiling sprinkler operation – Test 3 (2 min 9 s).

Figure 3.4.2-5: Photo of controlled fire – Test 3 (10 min).

Figure 3.4.2-6: Post-test photo of array – Test 3 (target array removed).

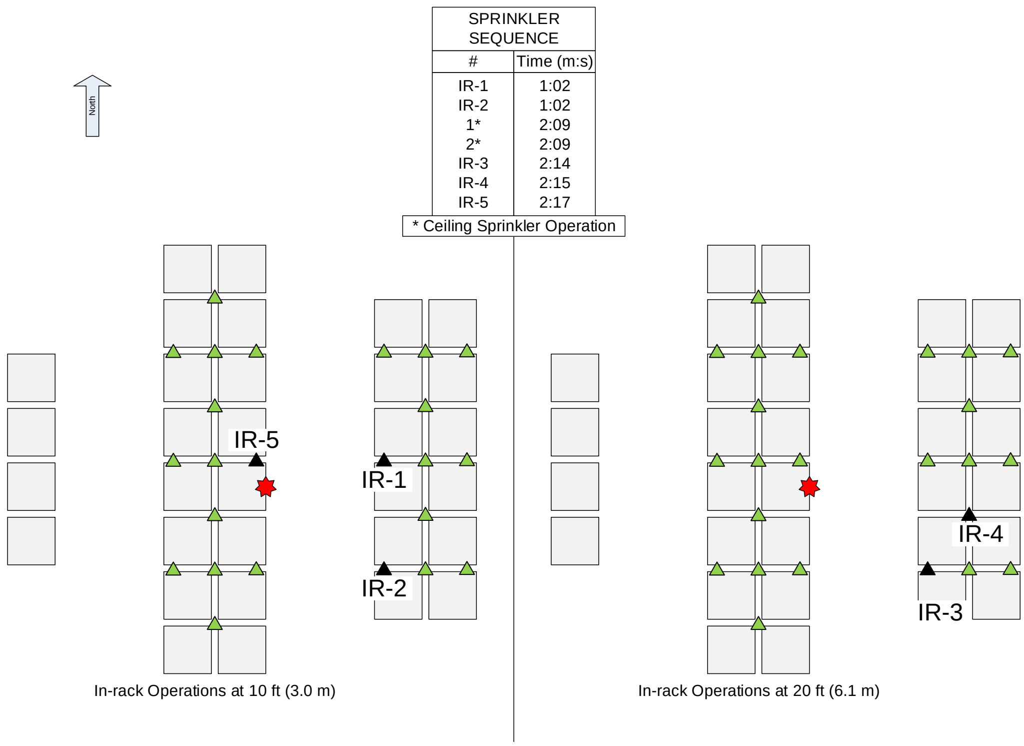


Figure 3.4.2-7: In-rack sprinkler operation pattern – Test 3.

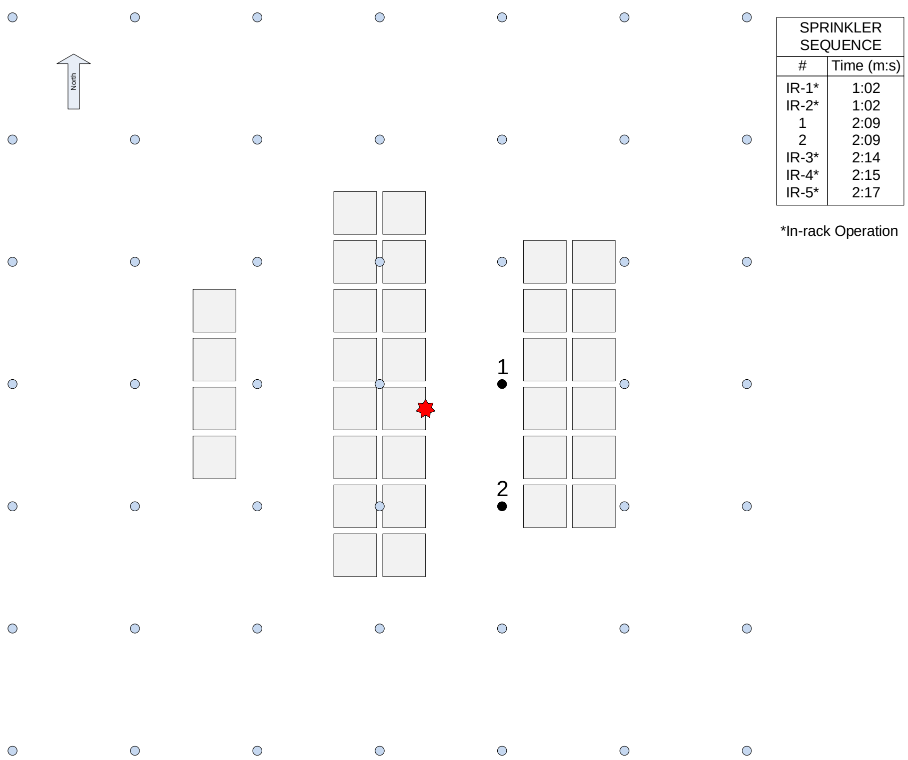


Figure 3.4.2-8: Ceiling sprinkler operation pattern – Test 3.

4. Discussion and Conclusions

4.1 Failure of Plastic Aerosol Containers

The use of a plastic container for an aerosol product contributed to the fire hazard observed during testing. In general, plastic bottle are less resistant to thermal exposure than metal aerosol containers. In comparison to data provided in Annex B of NFPA 30B [2], the cartoned plastic aerosol containers fail earlier than cartoned metal containers in similar rack storage fires. As noted in NFPA 30B, "there is usually a flame 5 ft to 10 ft (1.5 m to 3.0 m) above the top of the array before the first aerosol can ruptures and aerosols become involved in the fire." Numerous times to first rupture have been provided for different products and storage arrangements, but generally the first rupture has been observed > 1 min 30 s after ignition for metal containers.

In the three tests of this series with plastic aerosol containers, ruptures were observed nominally when the flames reached the top of the first tier and started to enter the second tier. This timing was well before flames extended above the top of the array. The first rupture times were observed at 36 s, 37 s, and 37 s in Test 1, Test 2, and Test 3, respectively. Both the stage of fire development within the rack and the time to rupture indicate that plastic bottles are less resistant to failure.

Upon each container rupture, a large fire ball, nominally 8 ft (2.4 m) in diameter, was generated. The primary fuel contributing to the fire ball was the hydrocarbon propellant present at the top of the bottle. As the bottle was exposed to fire, the headspace portion failed first, allowing the propellant to be released. The headspace portion of the bottle failed first since there was no heat-sink (liquid) to aid in absorbing the energy from the fire. Once released, the alcohol mix remained in the bottle for further local contribution to the fire as the plastic was consumed.

A variety of failure points can be seen and the overall damage of a bottle is based on the details of the bottle interaction with the fire. Bottles directly exposed to the fire breached at the top of the bottle as described above. Bottles that were not directly exposed, began to extrude as the plastic was heated. These extrusions were located at both the top and bottom of the bottle, but eventually led to failure and release of the product.

During the three tests, rocketing of containers outside the array was observed, but was limited in quantity. None of the bottles that rocketed from the array were on fire, though ethanol/water mix was observed inside some of the containers post-test, indicating the potential for fire spread via rocketed containers.

4.2 Ceiling-only Sprinkler Protection

In Test 1 and Test 2, ceiling only sprinkler protection was assessed for the cartoned plastic aerosol hazard. In Test 1, a limited footprint rack array had an overall storage height of 20 ft (6.1 m). In Test 2, a full footprint rack array had an overall storage height of 15 ft (4.6 m). In both tests, ceiling only protection was provided by K-factor 14.0 gpm/psi$^{1/2}$ (200 lpm/bar$^{1/2}$) pendent QR sprinklers with a 155^{o}F (68 ^{o}C) bulb, discharging at 75 psi (5.2 bar). Installed on 10 ft x 10 ft (3.0 m x 3.0 m) spacing, they provided a discharge density of 1.2 gpm/ft² (49 mm/min). The ceiling height was set to 30 ft (9.1 m) for both tests.

In Test 1, 11 sprinklers operated, exceeding the 8-sprinkler criterion set for the program. In addition, the fire reached to the CUP commodity outside the aerosol footprint, providing an inconclusive result for fire spread. In Test 2, 18 sprinklers operated, including six on the ceiling perimeter. These two tests demonstrated that ceiling only sprinkler protection was not sufficient to control the fire hazard of plastic aerosols stored beneath a 30 ft (9.1 m) ceiling.

4.3 Fire Protection System Design Scheme A

In Test 3, Fire Protection System Design Scheme A was assessed for adequate protection of rack-stored cartoned plastic aerosol containers. Four tiers, nominally 20 ft (6.1 m), of cartoned aerosols were stored in-racks beneath Scheme A protection. An additional tier of cartoned unexpanded plastic (CUP) commodity brought the overall storage height to 25 ft (7.6 m). The ceiling height was 30 ft (9.1 m) for the test.

The Scheme A protection was comprised of horizontal barriers and in-rack sprinklers placed at 10 ft (3.0 m) vertical intervals in the rack array. Beneath each horizontal barrier, in-rack pipes were positioned over the center longitudinal flue and at both faces of the array. Sprinklers were installed on 4 ft (1.2 m) spacing on the longitudinal pipe and on 8 ft (2.4 m) spacing on the face pipes. All in-rack sprinklers were K-factor 8.0 gpm/psi$^{1/2}$ (160 lpm/bar$^{1/2}$) pendent QR sprinklers with a 155°F (68°C) bulb. The in-rack sprinkler design pressure was 50 psi (3.5 bar), resulting in a flow of 57 gpm (216 lpm) per sprinkler. A full description of Fire Protection System Design Scheme A has been provided in Section 3.4.1.

In addition to Scheme A protection, ceiling level protection was provided by K-factor 14.0 gpm/psi$^{1/2}$ (200 lpm/bar$^{1/2}$) pendent QR sprinklers with a 155°F (68°C) bulb, discharging at 50 psi (3.5 bar). Installed on 10 ft x 10 ft (3.0 m x 3.0 m) spacing, they provided a discharge density of 1.0 gpm/ft² (41 mm/min).

In Test 3, five in-rack sprinklers and two ceiling sprinklers operated and controlled the cartoned plastic aerosol fire to the area of ignition. In-rack sprinklers operated in both the main array and target array and at both the 10 ft (3.0 m) and 20 ft (6.1 m) level. All evaluation criteria were met and the protection scheme worked well against the hazard.

The failure method of the plastic aerosol containers provided a unique challenge to the fire protection system. Upon rupture of the aerosol containers, the fire balls spread across the 8 ft (2.4 m) aisle and impacted the target array. The energy from the fire balls was sufficient to operate in-rack sprinklers in the target before in-rack sprinklers in the main array operated[8]. As the fire progressed, an in-rack sprinkler in the main array also operated and quickly suppressed the fire. However, this unique operation pattern should be considered when specifying appropriate fire protection.

[8] For solid combustibles, initial fire growth would cause in-rack sprinklers to operate in the main array prior to fire development being sufficient to operate an in-rack sprinkler in an adjacent rack.

Two ceiling sprinklers also operated during the test. Both ceiling sprinklers were located above the target array over the east aisle. The ceiling sprinklers operated at 2 min 9 s followed quickly by three in-rack operations between 2 min 14 s and 2 min 17 s. Based on observations from the test, the primary fire suppression was achieved with the in-rack sprinkler in the main array over ignition at 2 min 17 s. Water from the ceiling sprinklers was reaching the floor in the aisle between the racks, but did not appear to have direct impingement on the fire. In addition, the presence of the horizontal barriers prevented water flow from ceiling sprinklers from moving easily through the array.

For this test, the ceiling sprinkler design was specified as K-factor 14.0 gpm/psi$^{1/2}$ (200 lpm/bar$^{1/2}$) pendent QR sprinklers discharging at 50 psi (3.5 bar). However, based on the observed lack of contribution to suppression from the ceiling sprinklers, sufficient protection is likely with a wider range of protection options. Ceiling sprinklers designed in accordance to the protection required for surrounding commodities should provide an appropriate level of ceiling protection for commodity stored above the Scheme A protection.

4.4 Application of Fire Protection System Design Scheme A to Level 2 and 3 Aerosol Products

Past FM Global fire testing of aerosol products in metal containers has shown that some containers catastrophically fail in a fire (failure time approximately 1 minute) while others leak through the valve opening (failure time approximately 30 seconds). When metal cans fail catastrophically a fireball is created involving the propellant and any liquid product that is ignitable. When metal cans leak they produce a jet fire that involves the propellant. In both cases, the key to achieving adequate fire protection is providing adequate cooling via automatic sprinklers. Ceiling only sprinkler protection is adequate for either container failure mode as long as the aerosol product is packaged in cartons. For uncartoned storage, ceiling-only protection is adequate for Level 2 aerosol products only.

The plastic aerosol products used in the test program described in this report had failure times similar to those of leaking type metal aerosols and they produced a large fireball similar to that of the metal aerosols that failed catastrophically. A ceiling only protection option could not be defined for the plastic aerosol products. Based on the testing results, the plastic aerosol product creates a more challenging fire hazard than cartoned or uncartoned metal aerosol products.

Fire Protection System Design Scheme A provides a high level of sprinkler discharge early in a rack fire. The combination of a lesser fire hazard product and the effectiveness of water in cooling metal aerosol cans to delay their failure indicates that the Scheme A protection approach can provide fully adequate fire protection for cartoned or uncartoned, Level 2 and 3 aerosol products. Looking at successful and unsuccessful full-scale fire tests of Level 2 and 3 aerosol products has not shown any significant jet fires or fireballs exposing target racks. It is not expected that in-rack sprinklers in adjacent racks would operate before in-racks in the rack of origin. In that case, the hydraulic design for Scheme A only needs to consider in-racks in the rack of origin operating.

5. Recommendations

Based on the results of large-scale fire testing with cartoned plastic aerosol containers, the following recommendations for adequate fire protection are made:

1. Define a new Plastic Aerosol Product group with the following attributes:
   a. Plastic aerosol containers with a total volume ≤ 34 oz (1.0 L).
      [Note: A 27 oz (800 mL) container was used for testing because it presented a worst-case fuel loading within a pallet load. The results of this test program also apply to 34 oz (1.0 L) containers.]
   b. Plastic aerosol containers with ≤ 50% alcohol, or ≤ Group 3 water miscible liquids.
   c. Plastic aerosol containers pressurized with ≤ 10% (by weight) hydrocarbon propellant.

2. Fire Protection System Design Scheme A can be used to protect unlimited height rack storage of this new cartoned plastic aerosol product.

3. Fire Protection System Design Scheme A can be used to protect unlimited height rack storage of cartoned and uncartoned rack storage of Level 2 and 3 aerosol products.

4. Define Fire Protection System Design Scheme A as follows:
   a. Horizontal barriers of plywood having a minimum thickness of 3⁄8 in. (10 mm) or of sheet metal of minimum 22 gauge thickness to be installed in accordance with figures (a) through (d) in Table 5.0-1, whichever is applicable. All aerosol product storage to be located beneath a barrier.
      [Note: The distance the sprinkler deflector should be below the barrier has been expanded to 10 in. (25 cm) to simplify in-rack installations. This should not significantly impact the sprinkler operating times.]
   b. Aisles between racks to be 8 ft (2.4 m)
   c. In-rack sprinklers to be installed in accordance with figure (a) through (d) in Table 5.0-1, whichever is applicable.
   d. In-rack sprinklers to meet the following requirements:
      (1) In-rack sprinklers to be ordinary temperature–rated quick-response sprinklers and have a nominal K-factor equal to or greater than 8.0 gpm/psi$^{1/2}$ (120 L/min/bar$^{1/2}$). Intermediate temperature sprinklers to be used where ambient conditions require.
      (2) In-rack sprinklers to be installed below each barrier level.
   e. For aerosol products in metal containers:
      (1) In-rack sprinklers to provide a minimum operating flow of 57 gpm (220 L/min).
      (2) For one barrier level, design to include the hydraulically most remote six sprinklers (three on two lines).
      [Note: This hydraulic design assumes a normal fire growth in the rack of origin.]
      (3) For two or more barrier levels, design to include the hydraulically most remote eight sprinklers (four on two lines).

(4) The minimum in-rack sprinkler discharge pressure to not be less than a gauge pressure of 10 psi (0.69 bar).

f. For Plastic Aerosol 3 products:

(1) In-rack sprinklers to provide a minimum operating flow of 57 gpm (220 L/min).

(2) The design to include the hydraulically most remote seven sprinklers on one level in one rack and the most remote seven sprinklers on one level in the adjacent rack (14 total in-rack sprinklers).

[Note: Since the ceiling level sprinklers did not contribute to the success of the fire test, they only need to be accounted for in the sprinkler water demand. This hydraulic design allows for sprinkler operation in an adjacent rack as well as a few ceiling sprinkler operations]

(3) The minimum in-rack sprinkler discharge pressure to be no less than a gauge pressure of 10 psi (0.69 bar).

g. Where adjacent rack bays are not dedicated to storage of aerosols, the barrier and in-rack sprinkler protection should be extended at least 8 ft (2.4 m) beyond the area devoted to aerosol product storage. In addition, barrier and in-rack sprinkler protection should be provided for any rack across the aisle within 8 ft (2.4 m) of the perimeter of the aerosol product storage.

h. Ceiling sprinkler demand not to be included in the hydraulic calculations for in-rack sprinklers.

i. Provide a minimum hose stream allowance of 250 gpm (950 L/min).

j. Water demand at point of supply to be calculated separately for in-rack and ceiling sprinklers and to be based on the greater demand.

k. Ceiling sprinklers to meet the following requirements:

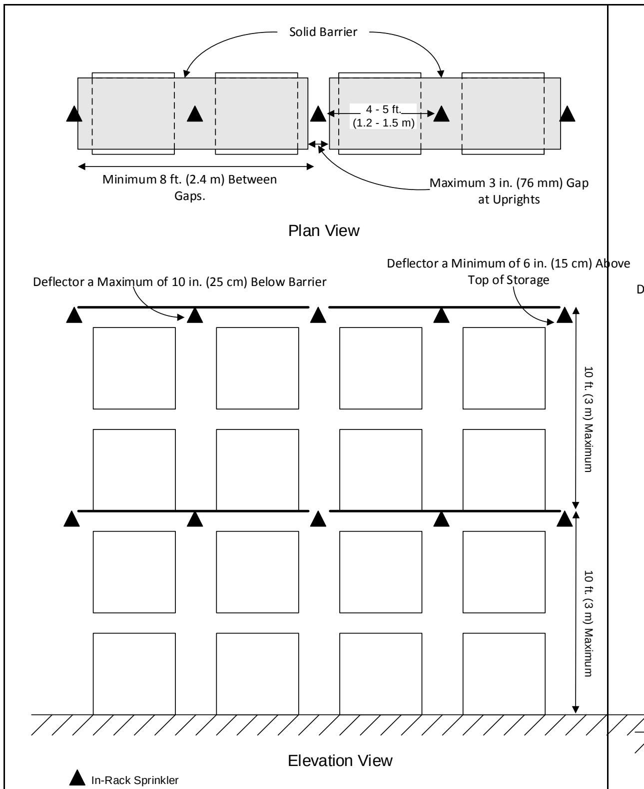
(1) Ceiling sprinkler protection to be designed to protect the surrounding occupancy.

(2) Any sprinkler type would be acceptable.

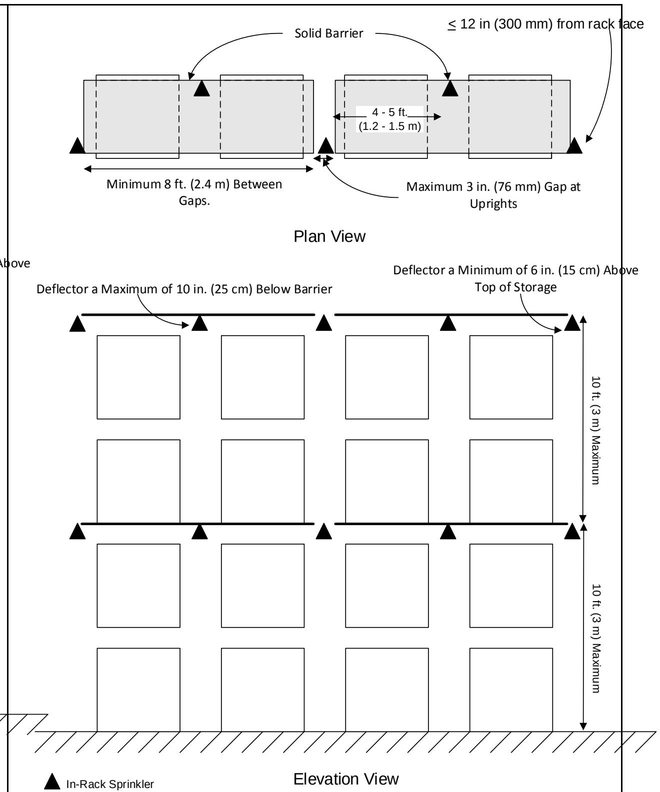
(3) If standard spray sprinklers are used, they should be capable of providing not less than 0.20 gpm/ft^2 (8 mm/min).

(4) If the aerosol product storage does not extend to the full height of the rack, protection for commodities stored above the top horizontal barrier should meet the requirements of NFPA 13, Standard for the Installation of Sprinkler Systems, for the commodities stored, based on the full height of the rack.

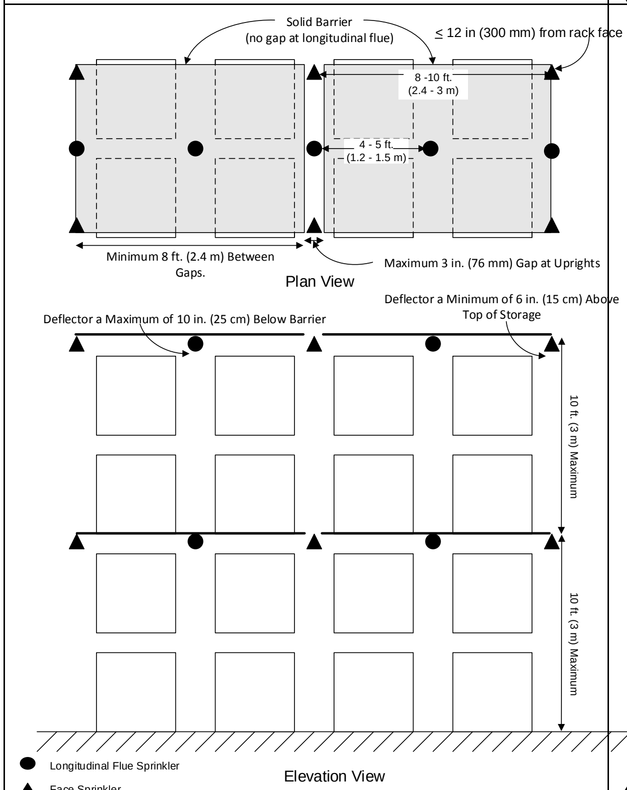
Table 5.0-1: Fire Protection System Design Scheme A Layout Figures



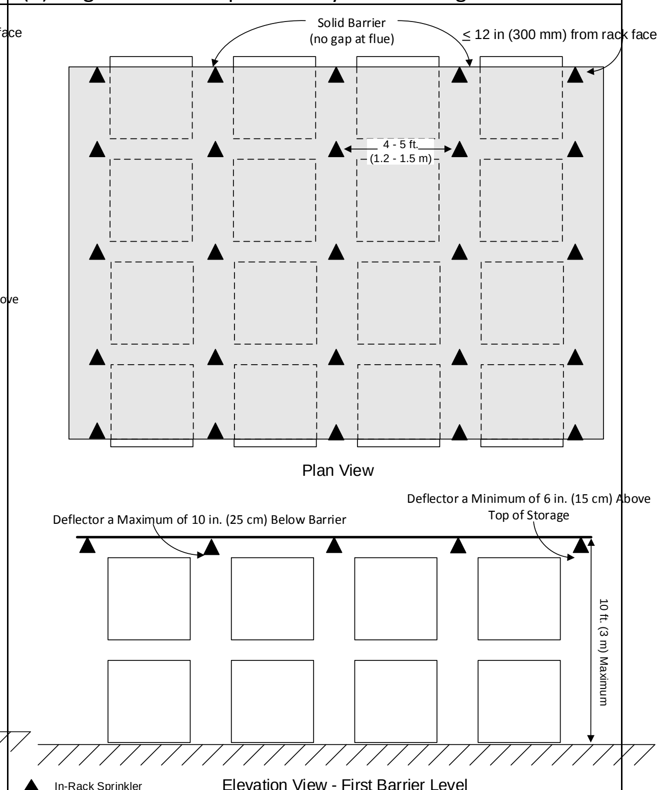
(a) Single Row Rack Sprinkler Layout for Design Scheme A



(b) Single Row Rack Sprinkler Layout for Design Scheme A



(c) Double Row Rack Sprinkler Layout for Design Scheme A



(d) Multiple Row Rack Sprinkler Layout for Design Scheme A

References

1. FM Global, Property Loss Prevention Data Sheet 7-31, Storage of Aerosol Products, January 2016 (Interim Revision April 2016).

2. National Fire Protection Association, NFPA 30B, Code for the Manufacture and Storage of Aerosol Products, 2015.

3. National Fire Protection Association, NFPA 13, Standard for the Installation of Sprinkler System, 2016.

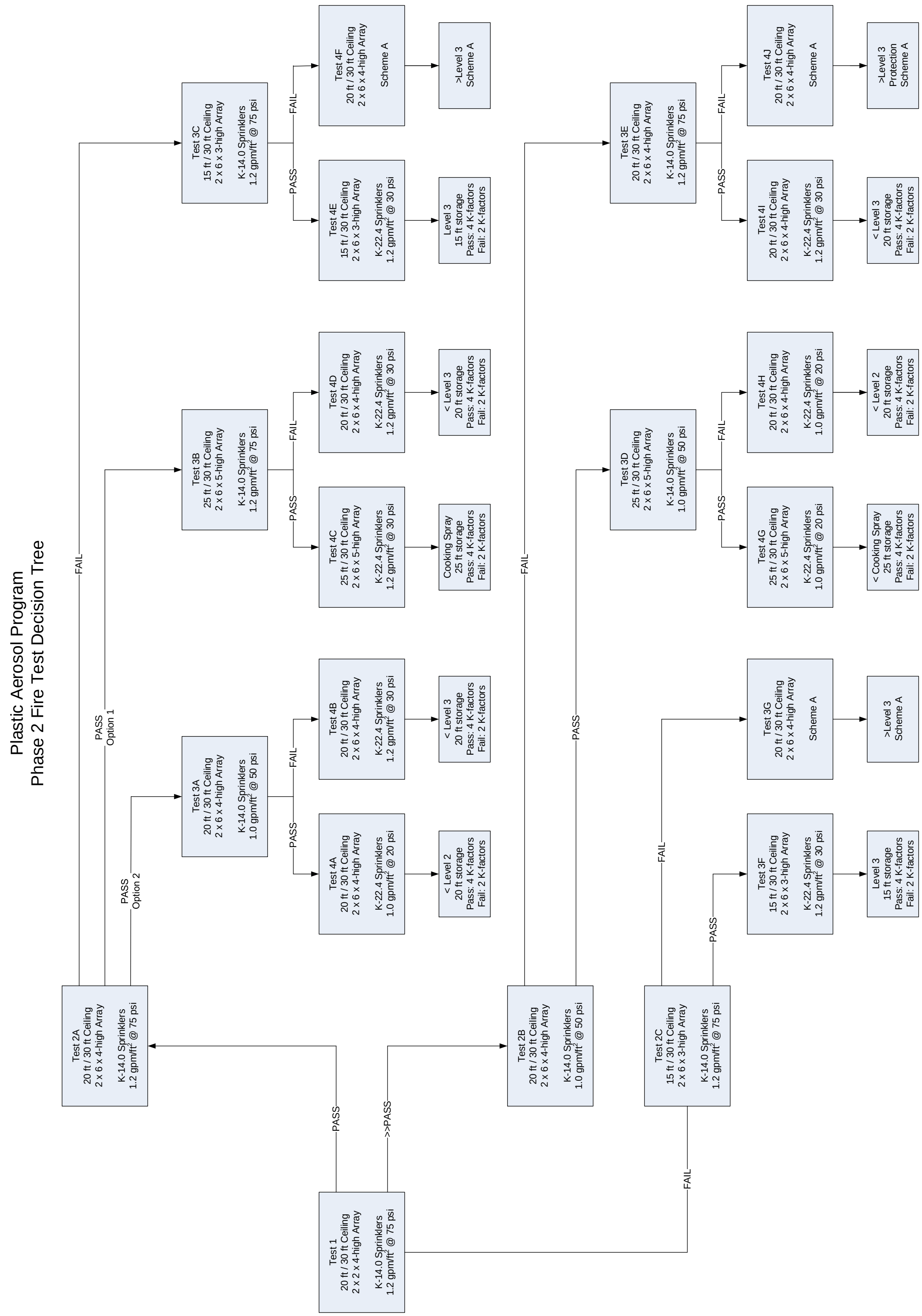
4. FM Global, Property Loss Prevention Data Sheet 7-29, Ignitable Liquid Storage in Portable Containers, April 2012 (Interim Revision July 2014).

5. FM Global, Property Loss Prevention Data Sheet 8-1, Commodity Classification, April 2014 (Interim Revision April 2015).

6. U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration, DOT-SP 20409, June 14, 2017.

7. Society of Fire Protection Engineers, "The SFPE Handbook of Fire Protection Engineering," National Fire Protection Association, Quincy, MA, 5th Edition, 2016.

Appendix A. Large-Scale Testing Decision Tree



Appendix B. Data Plots

B.1 Test 1 Data Plots

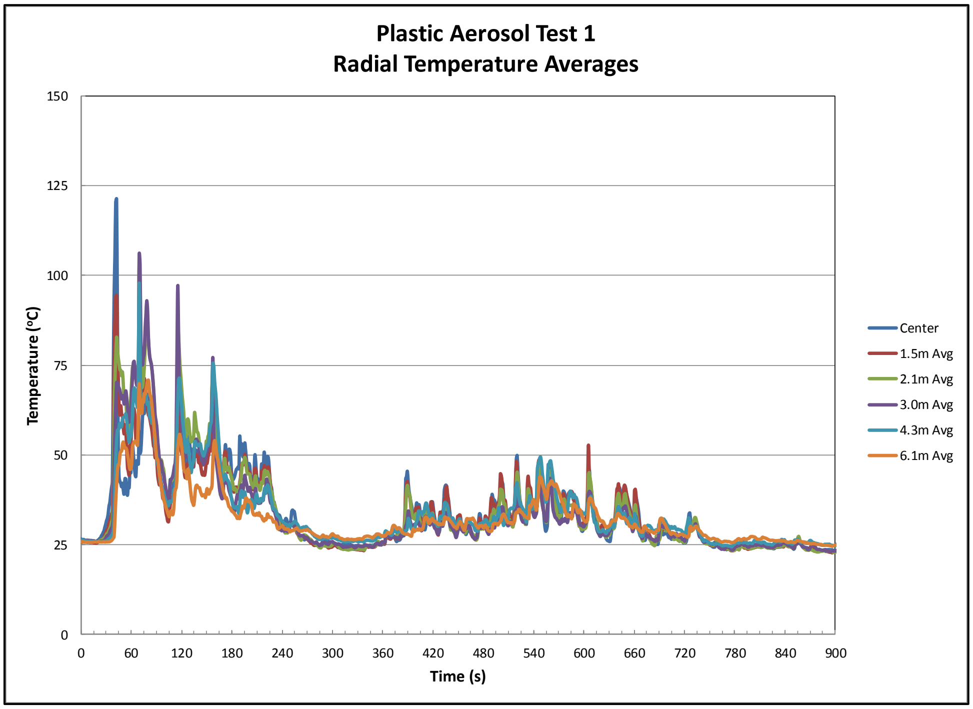


Figure B.1-1: Ceiling radial temperature averages – Test 1.

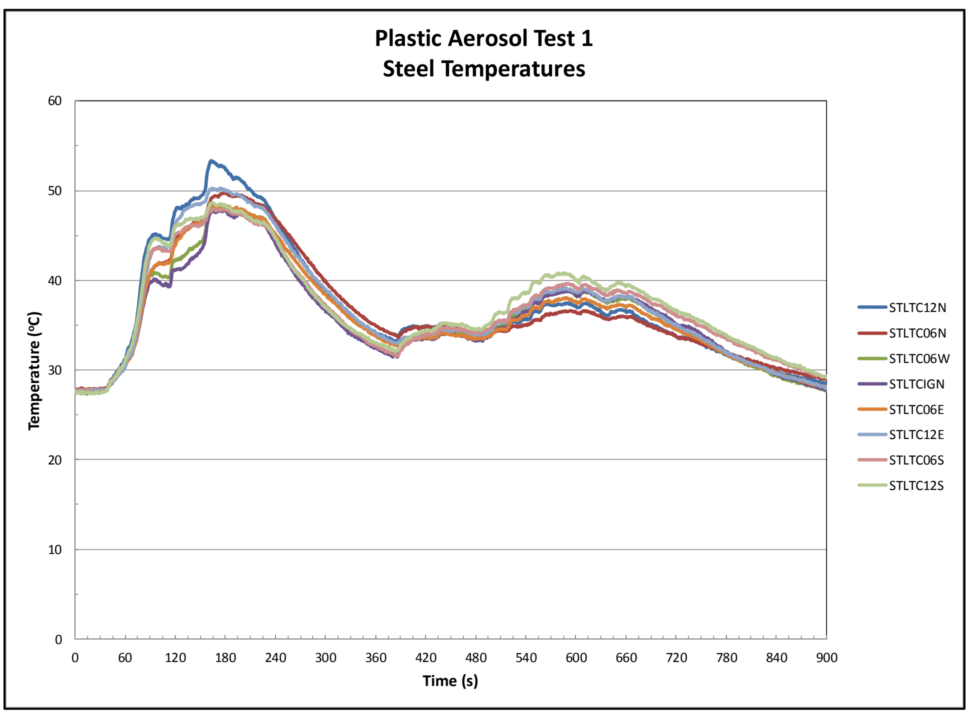


Figure B.1-2: Ceiling steel temperatures – Test 1.

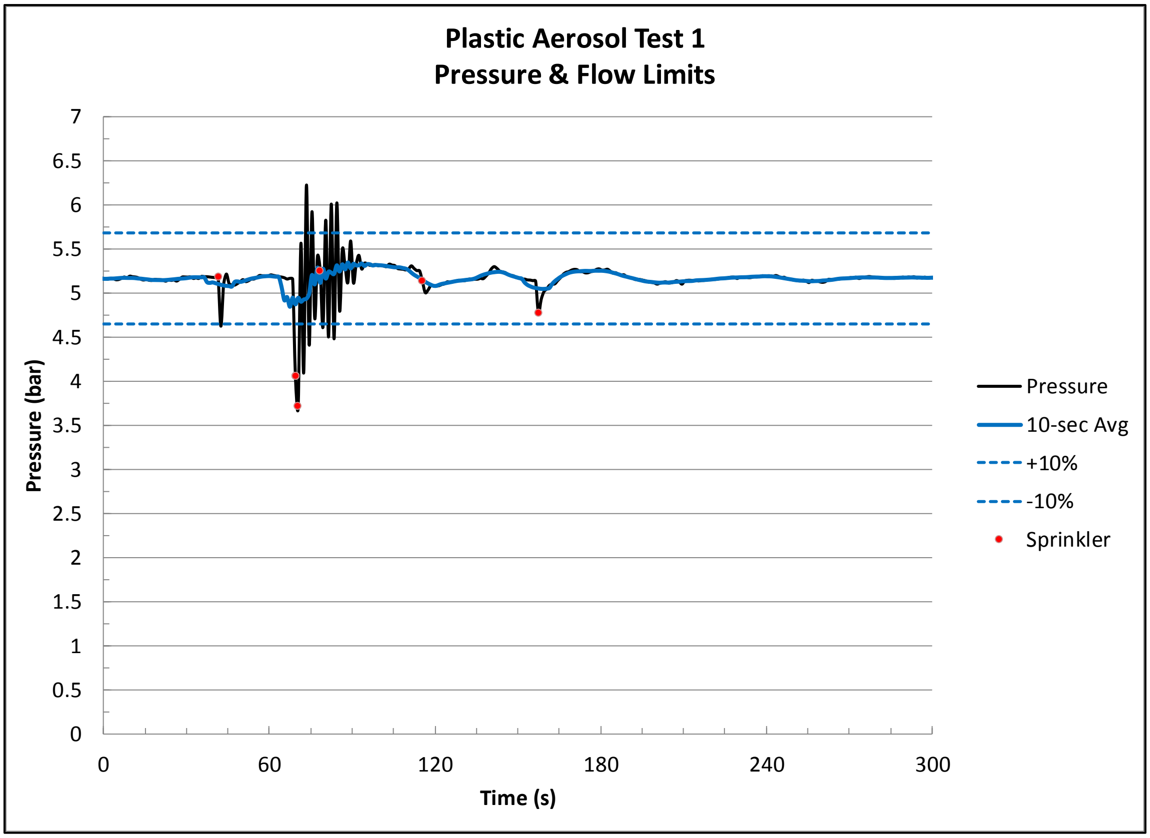


Figure B.1-3: Ceiling sprinkler pressure – Test 1[9].

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[9] Pressure control is assessed based on a criterion of maintaining the 10-second average pressure within ±10% of target pressure.

B.2 Test 2 Data Plots

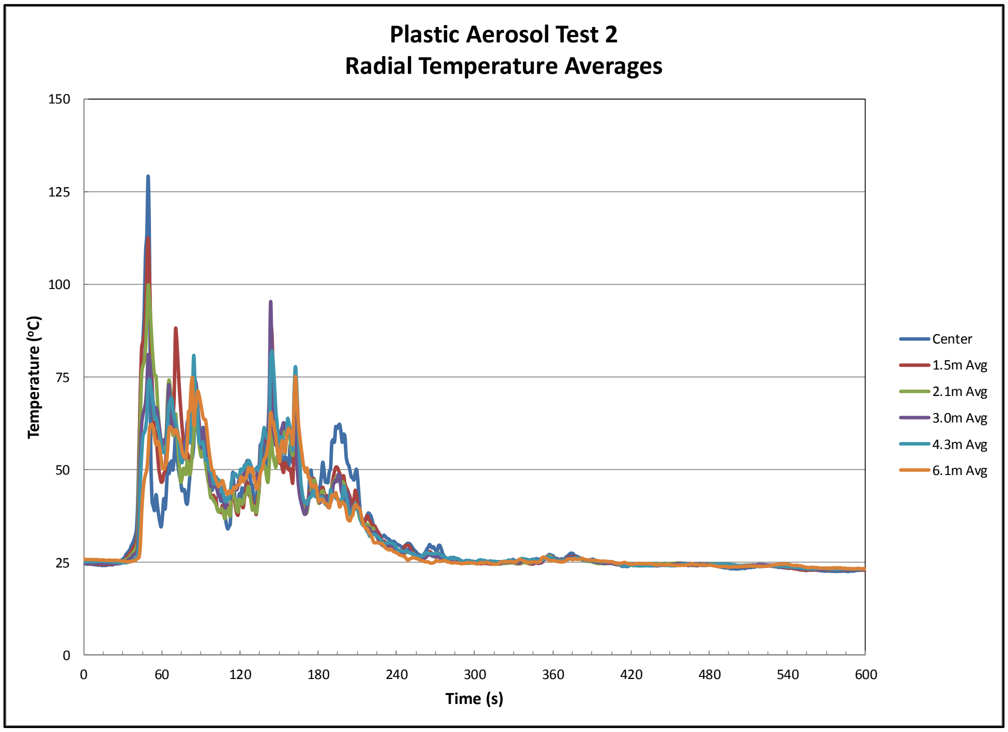

Figure B.2-1: Ceiling radial temperature averages – Test 2.

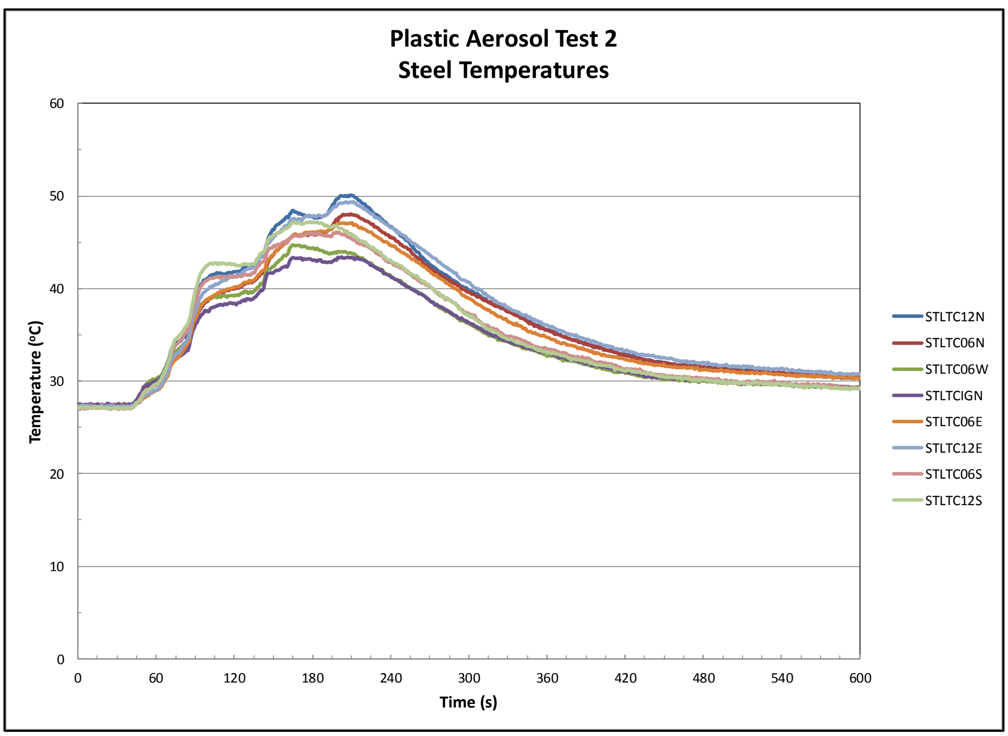

Figure B.2-2: Ceiling steel temperatures – Test 2.

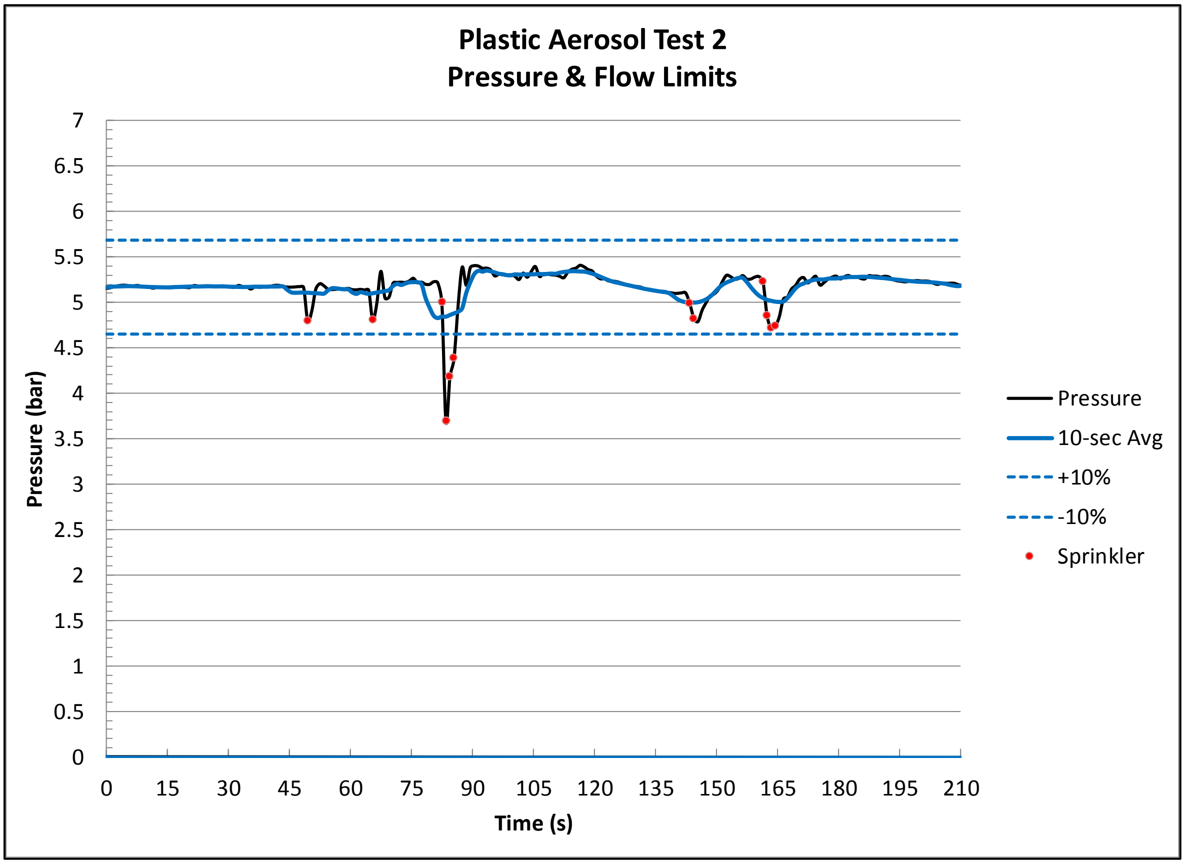

Figure B.2-3: Ceiling sprinkler pressure – Test 2.

B.3 Test 3 Data Plots

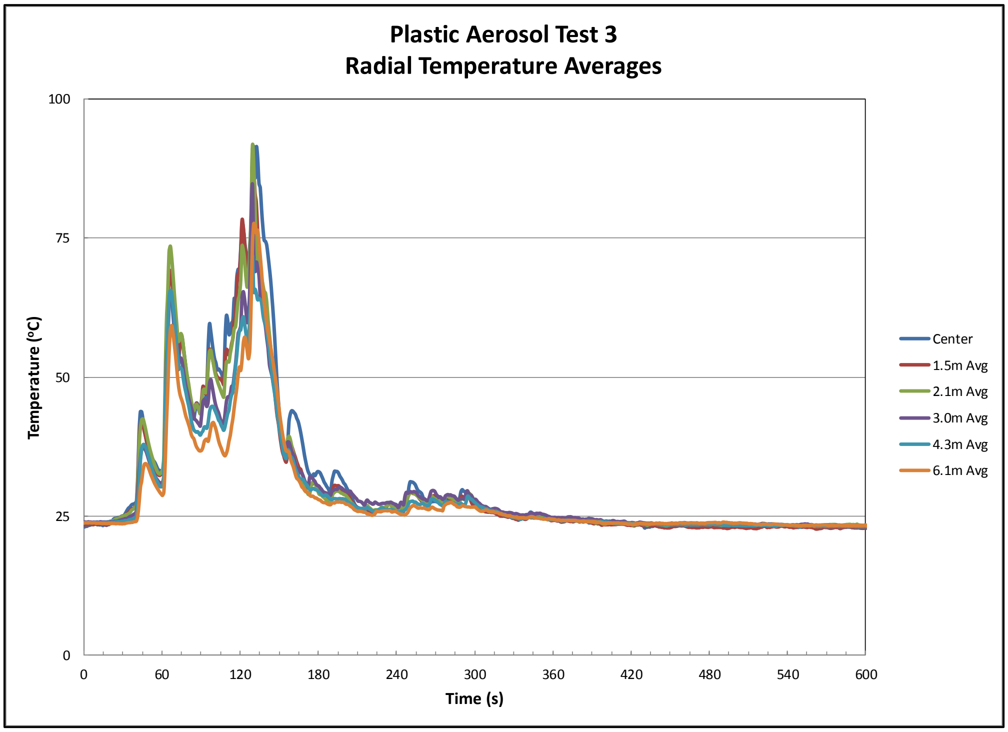

Figure B.3-1: Ceiling radial temperature averages – Test 3.

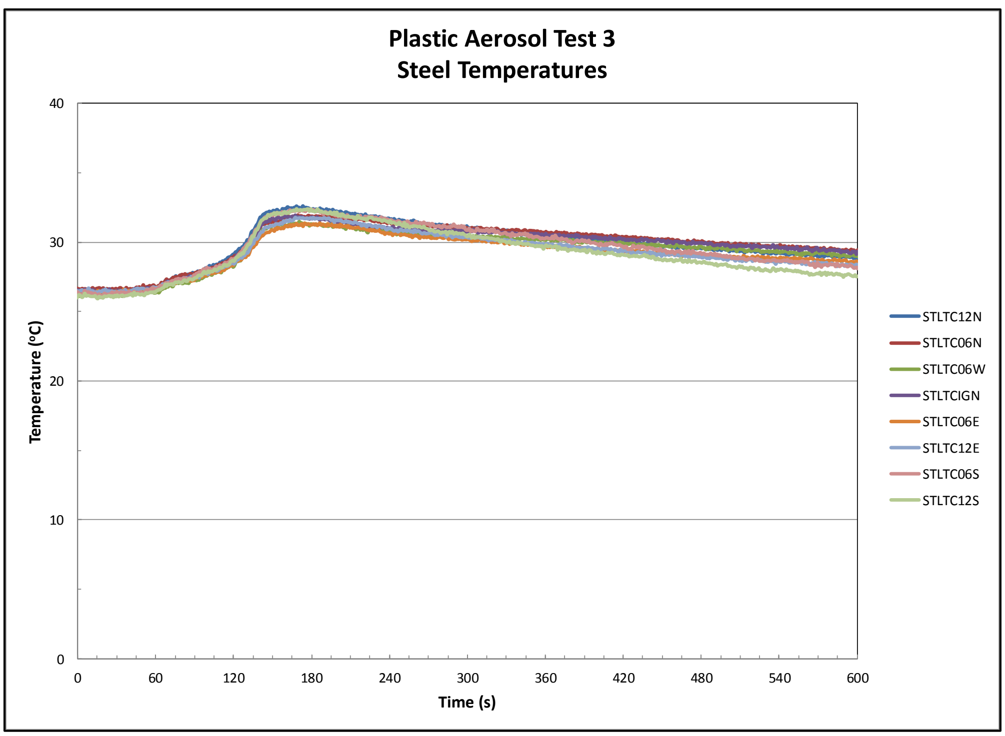

Figure B.3-2: Ceiling steel temperatures – Test 3.

B.4 Test 3 Sprinkler Pressure Plots

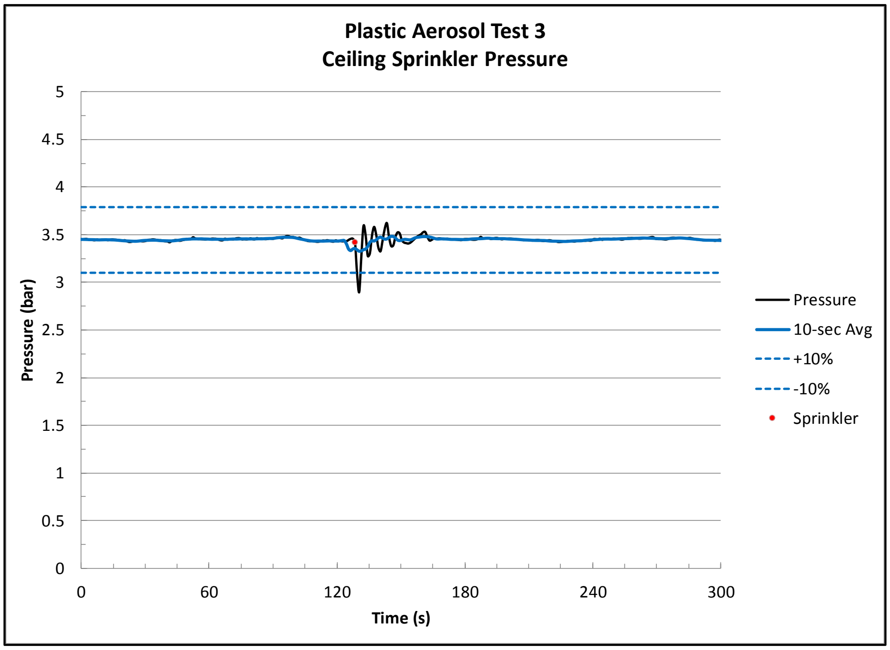

Figure B.4-1: Ceiling Sprinkler Pressure – Test 3.

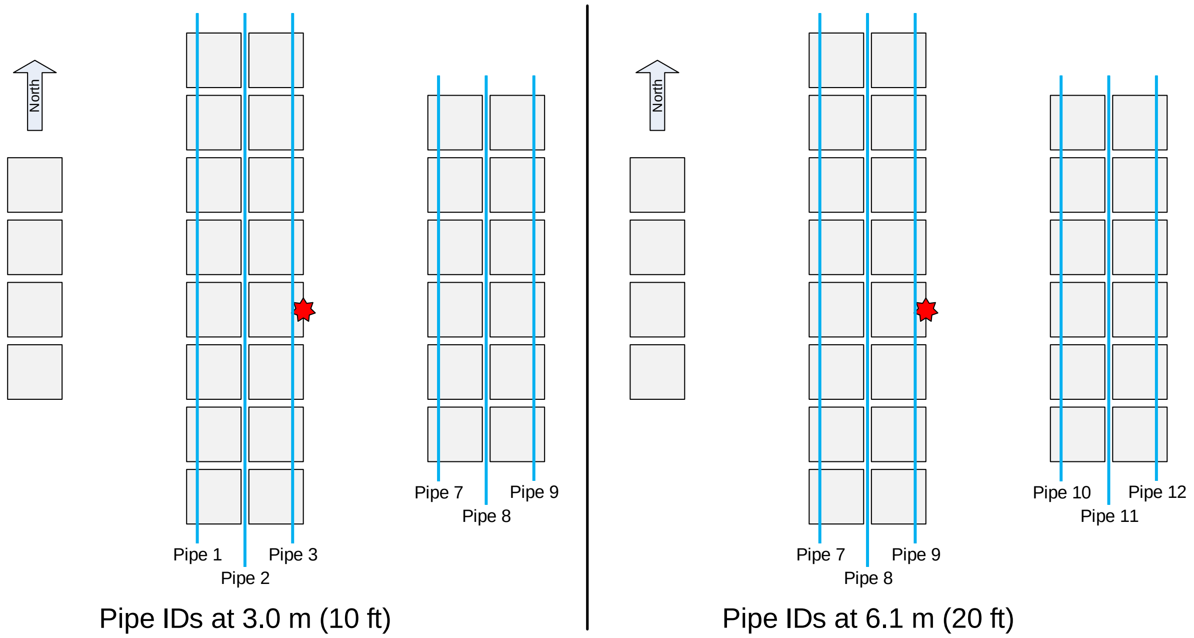

Figure B.4-2: Pipe identification per tier – Test 3.

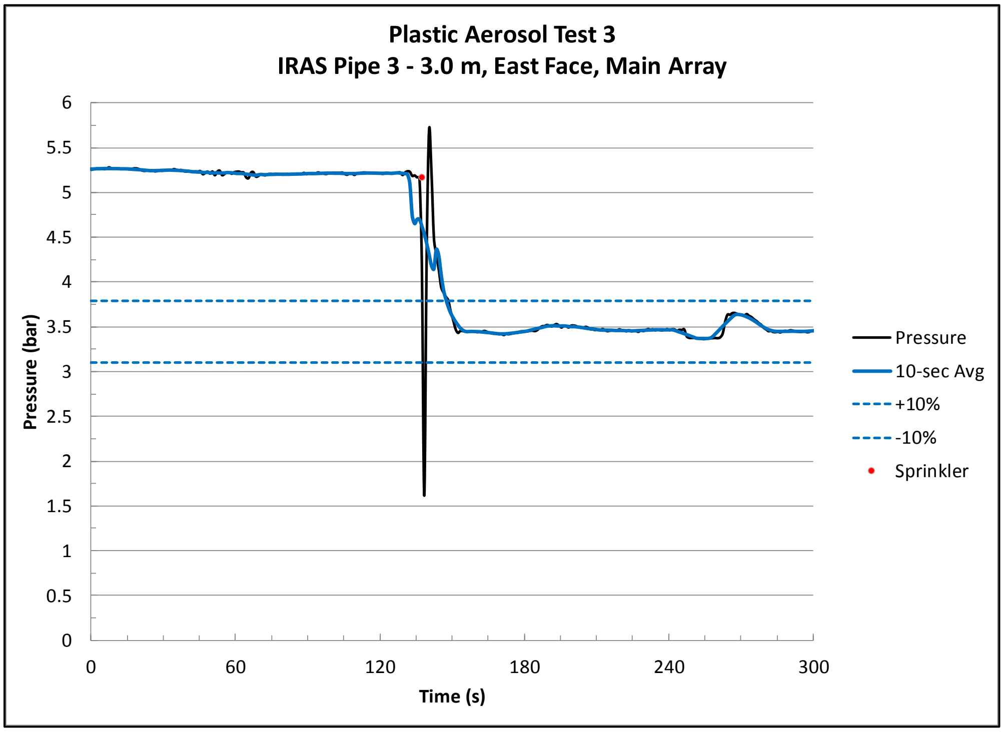

Figure B.4-3: IRAS Pipe 3 Sprinkler Pressure – Test 3.

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