Fire Performance Evaluation of a K-16.8 Suppression-mode Upright Sprinkler

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ABSTRACT: Five large-scale rack-storage fire tests and supplemental Actual-Delivered-Density (ADD) measurements were conducted to determine whether a K-16.8, quick-response, upright sprinkler could provide fire suppression performance under horizontal ceilings 9.1 m and 10.7 m high. The designated sprinkler operating pressures were 241 and 345 kPa, respectively. The sprinkler spacing used in this evaluation was 3.1×3.1 m. The fire hazard targeted under the 9.1-m high ceiling was up to that represented by rack-storage, expanded Group A plastics in cartons, and the fire challenge under the 10.7-m high ceiling was up to that of unexpanded Group A plastics in cartons, also stored in steel racks. In these tests, the prototype sprinkler demonstrated fire protection performance expected from a suppression-mode sprinkler within its intended applications. One of the tests conducted under the 9.1-m high ceiling showed that the sprinkler's performance was little affected by the presence of a building bar joist obstruction investigated in this program.

KEY WORDS: suppression-mode upright sprinkler, bar-joist obstruction.

INTRODUCTION

THE EARLY-SUPPRESSION-FAST-RESPONSE (ESFR) Sprinkler Research Program [1], initiated by FM Global Research in 1983, ushered in a new era of fire sprinkler development for warehouse protection. Based on the design guidelines and specifications resulting from this research program, a

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family of suppression-mode pendent sprinklers was subsequently developed in the fire sprinkler industry [2,3]. The nominal sprinkler discharge K-factors of these suppression-mode pendent sprinklers currently range from 20 to 36 $dm^3/min/kPa^{1/2}$ (14–25 $gpm/psi^{1/2}$). These sprinklers are capable of protecting high fire-challenging commodities without the need of in-rack sprinklers. However, the effectiveness of these suppression-mode pendent sprinklers tends to be adversely affected by obstructions present in the building, such as bar joists, bridging, lighting fixtures, and ventilation ductwork [4]. As a result, these sprinklers have to follow strict installation guidelines with respect to obstructions in order to maintain their effectiveness [5]. These guidelines frequently cause installation inconvenience and increase of system cost.

The fire protection industry has always desired a suppression-mode upright sprinkler. An upright model would be easier to retrofit into existing upright sprinkler piping systems, and the effectiveness of an upright sprinkler tends to be less negatively affected by building obstructions. Such impetus prompted the development of suppression-mode upright sprinklers with nominal K-factors of 15.9 and 20.2 $dm^3/min/kPa^{1/2}$ (K-11 and K-14 sprinklers) in the late 90s [6]. The K-11 sprinklers operating at 345 kPa (50 psig) are intended to protect commodities with fire hazard levels up to unexpanded Group A plastics in cartons under ceilings up to 7.6 m (25 ft) high. The K-14 sprinklers are intended to protect commodities up to (1) expanded Group A plastics in cartons stored under ceilings up to 9.1 m (30 ft) high with an operating pressure of 345 kPa (50 psig), and (2) unexpanded Group A plastics in cartons stored under ceilings up to 10.7 m (35 ft) high with an operating pressure of 517 kPa (75 psig). A test protocol was later developed based on this research work to evaluate other suppression-mode upright sprinklers [7].

In 2000, a research program was initiated to determine whether an upright sprinkler with a K-factor larger than 20.2 $dm^3/min/kPa^{1/2}$ (14 $gpm/psig^{1/2}$) could provide fire suppression performance comparable to that of the K-14 upright sprinkler but with lower operating pressures. A K-factor of 24.2 $dm^3/min/kPa^{1/2}$ (16.8 $gpm/psi^{1/2}$, referred to later as K-16.8 sprinklers) was selected because it was about the largest orifice that could be obtained for sprinklers with a 19-mm ($\frac{3}{4}$-in.) pipe thread without compromising the sprinkler's mechanical strength. The designated operating pressures of the K-16.8 sprinkler were 241 and 345 kPa (35 and 50 psig) for the protection of 9.1-m (30 ft) and 10.7-m (35 ft) high buildings, respectively, to produce the sprinkler water discharge rates of the K-14 sprinkler operating at 345 and 517 kPa (50 and 75 psig).

A series of Actual-Delivered-Density measurements [1] were conducted to optimize the sprinkler deflector geometry to obtain spray patterns adequate for the designated fire challenges. The prototype sprinkler was equipped

Figure 1. *The prototype sprinkler used in the large-scale fire tests.*

with a fusible link having a temperature rating of 74°C (165°F) and an RTI (Response Time Index) value of 25 $(m\,s)^{1/2}$ (45 $(ft\,s)^{1/2}$). A photograph of the optimized sprinkler is shown in Figure 1.

This paper describes five large-scale fire tests conducted following the requirements of the test protocol developed previously [7] to evaluate the fire protection performance of the prototype K-16.8 sprinkler for the fire challenges described above. Of the five large-scale tests, three were conducted under a 9.1-m (30 ft) high ceiling and two were conducted under a 10.7-m (35 ft) high ceiling. The impact of a building bar joist obstruction on the K-16.8 sprinkler's fire suppression effectiveness was examined in one of the three tests conducted under the 9.1-m (30 ft) high ceiling. In each of the large-scale fire tests, 49 sprinklers were installed below the ceiling in a 7 × 7 matrix with a sprinkler spacing of 3.1 m × 3.1 m (10 ft × 10 ft).

LARGE-SCALE FIRE TEST SETUPS AND PROCEDURES

Five large-scale fire tests were conducted in the FM Global Technology Center building located in West Glocester, Rhode Island. The building has a floor plan of 61 m × 76 m (200 ft × 250 ft) under one flat ceiling, which consists of two test areas with ceiling heights of 9.1 m (30 ft) and 18.3 m (60 ft), respectively. Of the five tests, three were conducted in the 9.1-m (30 ft) test area and the other two were conducted in the 18.3-m (60 ft) area. A 7.6-m (25 ft) high steel platform was used in the 18.3-m (60 ft) area to render a ceiling height of 10.7 m (35 ft) above the platform. Described in the following subsections are the commodities, storage arrangements, sprinkler layout, instrumentation, ignition method, and test procedures.

Test Commodities

Two types of plastic commodities in cartons were used to challenge the prototype sprinkler: polystyrene meat trays in cartons and polystyrene cups in cartons. The former is classified as an expanded Group A plastic commodity in cartons, and the latter is an unexpanded Group A plastic commodity in cartons, according to FM Global Property Loss Prevention Data Sheet 8-1 [8] and the National Fire Protection Association Standard 231C [9].

The polystyrene-cup commodity in cartons, also known as Standard Plastic Commodity for fire evaluation of sprinkler performance in the fire sprinkler industry [8], comprised polystyrene cups in compartmented, single-wall, corrugated cardboard cartons. Eight such $0.53\,\text{m} \times 0.53\,\text{m} \times 0.53\,\text{m}$ (21 in. × 21 in. × 21 in.) high cartons were placed on a wood pallet in a $2 \times 2 \times 2$ configuration to make a pallet load. In each carton there were 125 polystyrene cups arranged in a $5 \times 5 \times 5$ matrix separated by vertical and horizontal cardboard dividers. The gross weight of a pallet load of the commodity was about 74.9 kg (165 lb), of which 40% was polystyrene cups, 29% was cartons and dividers, and 31% was the wood pallet.

The meat-tray commodity in cartons was made by packaging 2.68 kg (5.9 lb) of foam polystyrene meat trays in each of the 0.53-m (21 in.) cube-shaped corrugated cardboard cartons. Like the other commodity, each pallet-load consisted of eight filled cartons stacked on a wood pallet. The gross weight of a pallet load of the meat-tray commodity in cartons was about 54 kg (119 lb), of which 40% was meat trays, 17% was cartons, and 43% was the wood pallet.

The polystyrene-cup commodity in cartons was used in Test 1 conducted under the 9.1-m (30 ft) high ceiling, and Tests 4 and 5 conducted under the 10.7-m (35 ft) high ceiling. The meat-tray commodity in cartons was used in Tests 2 and 3 conducted under the 9.1-m (30 ft) high ceiling.

The moisture content of the corrugated cardboard cartons measured before Tests 1–5 was 8.2, 6.5, 6.4, 6.9, and 4.7%, respectively.

Layouts of Sprinklers and Storage Arrays for 9.1-m (30 ft) High Ceiling Tests

One of the findings obtained from the previous ESFR research program is that the two most challenging fire locations relative to sprinklers are (1) fire starts directly under one of the ceiling sprinklers with appreciable ceiling clearance above the storage array, and (2) fire starts between two sprinklers with relatively low ceiling clearance [10]. The former scenario tests the sprinkler spray's fire plume penetration capability; the latter scenario ensures that sufficient overlapping of sprinkler sprays is achieved.

Of the three tests conducted under the 9.1-m (30 ft) high ceiling, Tests 1 and 2 were conducted with the ignition location centered below two sprinklers (below-two), and Test 3 was conducted with the ignition location centered under one sprinkler (under-one). The designated ceiling clearance above the storage arrays was 3.2 m (10.5 ft) for the under-one scenario, and 1.6 m (5.5 ft) for the below-two scenario. The pallet loads of commodities were arranged in steel racks and were separated with 0.15-m (6-in.) wide vertical flues in both the longitudinal and transverse directions [7]. The nominal height per tier was 1.5 m (5 ft).

SETUP OF TEST 1

Figure 2 illustrates the storage arrays used in Test 1, which consisted of a main array and a target array separated with a 1.2-m (4 ft) wide aisle. Figure 3 shows the locations of the storage arrays relative to the installed sprinklers. The main array was a seven-pallet-loads deep, double-row rack storage and the target array was a four pallet-load deep, single-row rack storage. Both the main array and the target array were five tiers (7.5 m or 24.5 ft) high.

This test was conducted to evaluate the sprinkler's performance under a simulated failure-mode situation where one of the two sprinklers closest to the ignition location was rendered inoperative throughout the test (see Figure 3). The polystyrene-cup commodity in cartons was used in this test in order to compare the sprinkler's performance to that of suppression-mode pendent sprinklers previously tested using the same commodity and test conditions. As required for suppression-mode pendent sprinklers, the total number of sprinkler actuations in this test should not exceed twelve [5].

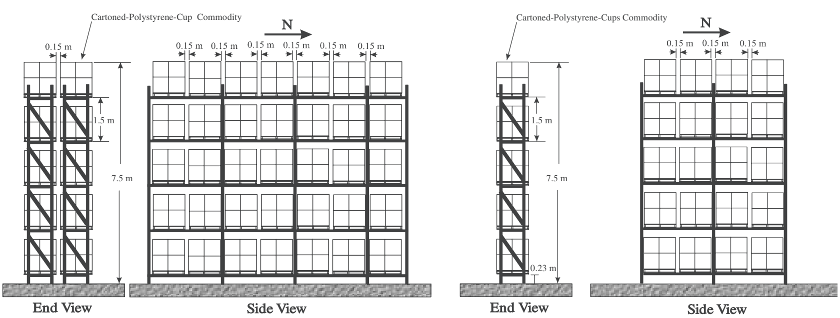


***Figure 2.** An illustration of the main storage array (on the left) and the target array (on the right) used in Test 1.*

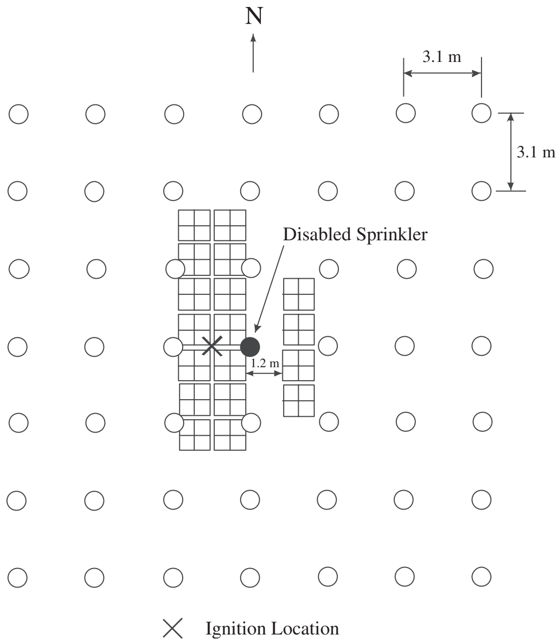


Figure 3. *A plan view of the sprinkler layout relative to the storage arrays used in Test 1. The test was conducted under a 9.1-m (30 ft) high ceiling. The branch lines were in the east-west direction.*

SETUP OF TEST 2

The storage arrays used in Test 2 also consisted of a main array and a target array. The meat-tray commodity in cartons was used in this test. The configurations of the storage arrays were almost identical to those of Test 1, except that the main array was six pallet-loads deep. Same as in Test 1, the main array and the target array were separated with a 1.2-m (4 ft) wide aisle as shown in Figure 4. The test was started by igniting the main array at the base of its central vertical flue. Like Test 1, the ignition was centered below two sprinklers.

SETUP OF TEST 3

Test 3 used a single six pallet-load deep, double-row rack storage array of four tiers (5.9 m or 19.5 ft) high, as shown in Figure 5. Figure 6 shows the location of the storage array relative to the installed sprinklers. The meat-tray commodity in cartons was used in this test. This test was conducted to: (1) evaluate the sprinkler's performance when the fire was started directly below a sprinkler, and (2) evaluate the impact of the presence of a building bar joist obstruction.

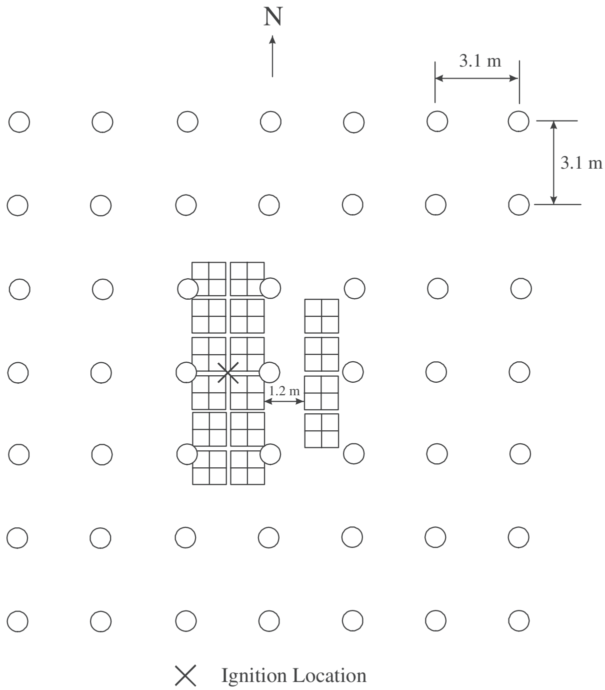


Figure 4. *A plan view of the sprinkler layout relative to the storage arrays used in Test 2. The test was conducted under a 9.1-m (30 ft) high ceiling. The branch lines were in the east-west direction.*

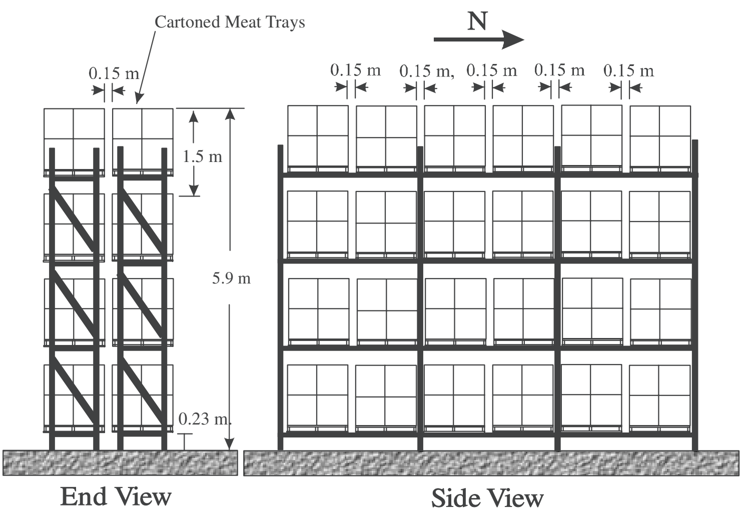


Figure 5. *An illustration of the storage array used in Test 3.*

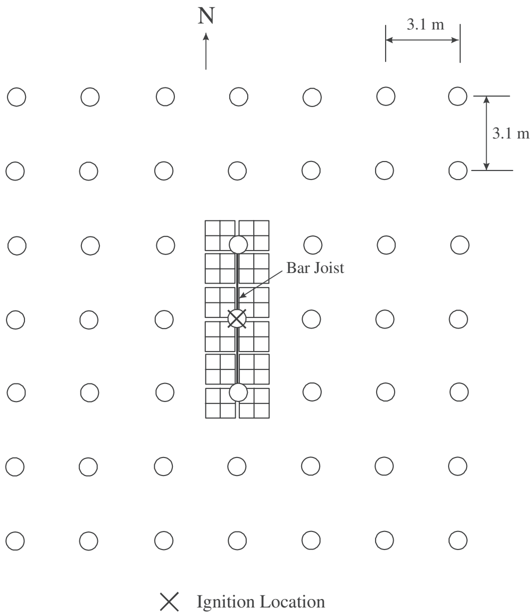


Figure 6. *A plan view of the sprinkler layout relative to the storage array used in Test 3. The test was conducted under a 9.1-m (30 ft) high ceiling. The branch lines were in the east-west direction.*

A bar joist would produce the worst obstruction effect if both the ignition location and the bar joist are centered under a sprinkler. In this test, a 43-mm (17 in.) high bar joist of 7.6 m (25 ft) long with a bottom chord of 100 mm (4 in.) wide was centered with respect to the center sprinkler of the 7×7 sprinkler matrix arrangement. To maximize the obstruction effect below the sprinkler, the bar joist's bottom chord was made abutted underneath the sprinkler pipe. The bar joist was perpendicular to the sprinkler pipe. The sprinkler over the ignition was centered in the V-shaped clearance between two adjacent 19-mm (3/4-in.) rods of the bar joist so that the horizontal distance from the sprinkler deflector to either rod was about 76 mm (3 in.). Figure 7 exhibits a pictorial illustration of the bar joist relative to the sprinkler and the branch line.

Layouts of Sprinklers and Storage Arrays for 10.7-m (35 ft) High Ceiling Tests

Test 4 was conducted with ignition location centered under one sprinkler and Test 5 was conducted with ignition centered below two sprinklers. The fire challenge in these two tests was provided with the

Figure 7. *A photograph of the bar joist obstruction used in Test 3.*

cartoned-polystyrene-cup commodity. Like the arrays used in the 9.1-m (30-ft) high ceiling tests, the pallet loads arranged in the steel racks were separated with 0.15-m (6-in.) wide vertical flues.

SETUP OF TEST 4

Figure 8 shows the storage array used in Test 4, which was two pallet-loads wide, four pallet-loads deep, and five tiers (7.5 m) high.

Figure 9 shows the location of the storage array relative to the installed sprinklers in Test 4.

SETUP OF TEST 5

Figure 10 shows the storage array used in Test 5. The extent of the array was two pallet-loads wide, six pallet-loads deep, and six tiers (9.0 m or 29.5 ft) high.

Figure 11 shows the location of the storage array relative to the installed sprinklers in Test 5.

In Tests 1–5, schedule-40, 2-in. branch lines (American National Standard pipe size with 60 mm OD and 53 mm ID) were used and their centerlines were positioned 0.31 m (12 in.) under the ceiling. However, in order to create a pipe shadow equivalent to that produced by schedule-40, 2.5-in. pipes (with 73 mm OD) in the fire area, the branch line directly above the fire origin was enclosed in concentric metal sleeves to augment the branch

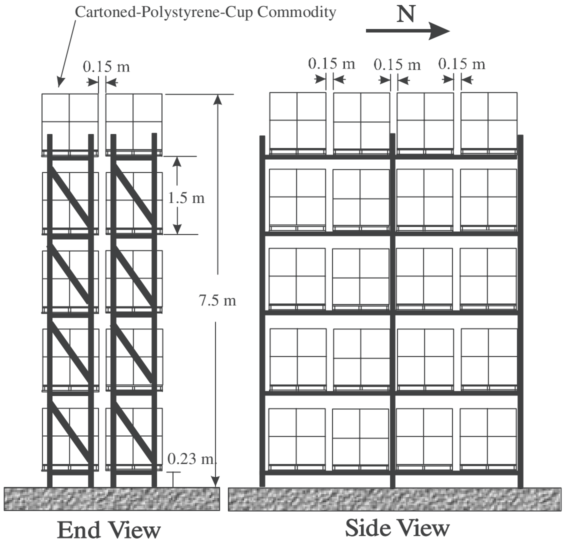


Figure 8. *An illustration of the storage array used in Test 4.*

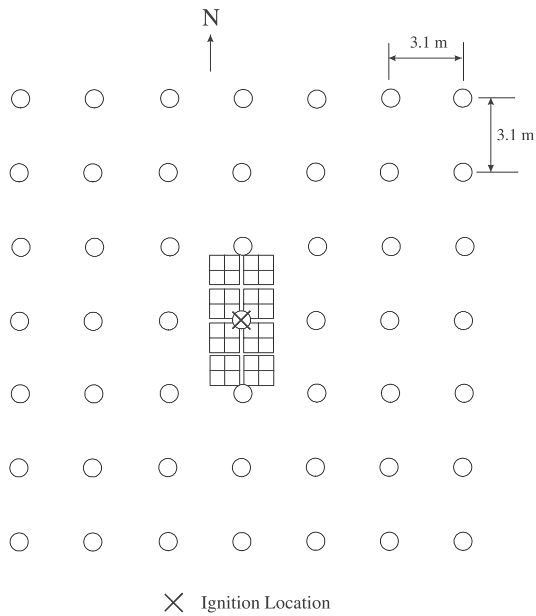


Figure 9. *A plan view of the sprinkler layout relative to the storage array used in Test 4. The test was conducted under a 10.7-m (35 ft) high ceiling. The branch lines were in the east-west direction.*

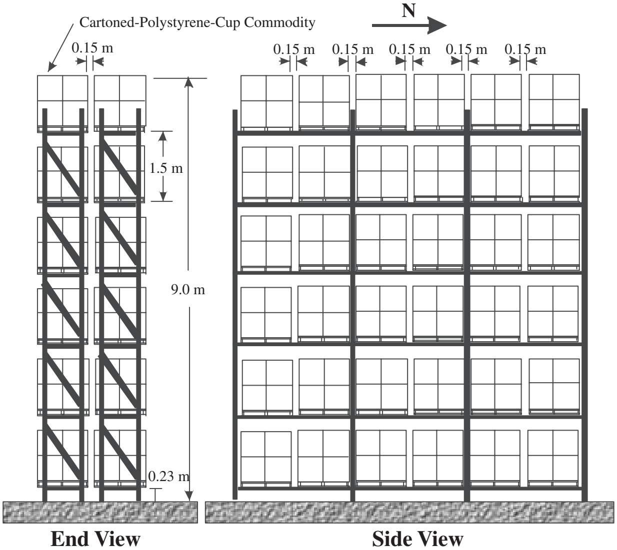


Figure 10. *An illustration of the storage array used in Test 5.*

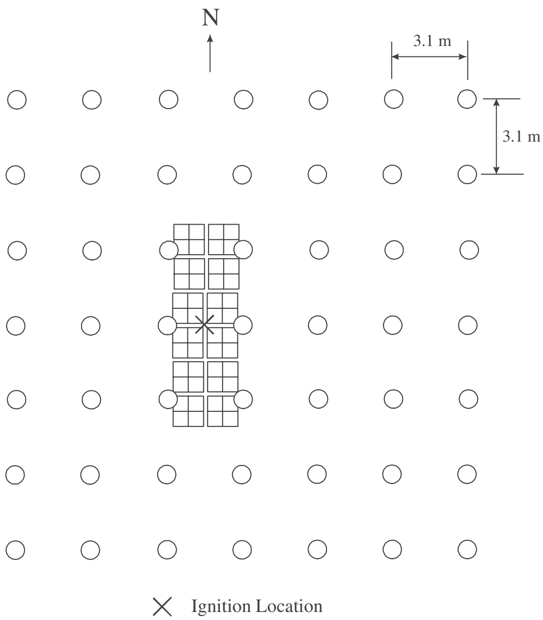


Figure 11. *A plan view of the sprinkler layout relative to the storage array used in Test 5. The test was conducted under a 10.7-m (35 ft) high ceiling. The branch lines were in the east-west direction.*

line's outside diameter to that of 2.5-in. pipes. The sprinklers were mounted directly to the tees; the sprinkler deflectors were 0.14 m (5.5 in.) above the pipe centerline.

Instrumentation

Measurements were made of the temperature of a steel angle installed underneath the ceiling and the sprinkler actuation times, as well as the near-ceiling gas temperatures and the fire radiant heat fluxes. The gas temperature measurements were used as supporting information to verify the sprinkler actuation events and to determine the test duration. The fire radiant heat flux measurements were used to help verify whether the fire would jump to a nearby storage array.

A steel angle, 51 mm × 51 mm × 6 mm (2 in. × 2 in. × $\frac{1}{4}$ in.) thick (4.8 kg/m or 3.2 lb/ft) and 1.2 m (4 ft) long, was installed underneath the ceiling in the east-west orientation with one flat surface in direct contact with the ceiling. The steel temperature was monitored with five 20-gage (0.8 mm diameter), fiberglass-sheathed, chromel–alumel thermocouples 0.15 m (6 in.) apart. These thermocouples were spot-welded on the steel angle surface with the center thermocouple located at the midpoint of the steel angle, which was in turn centered directly above the ignition location.

Each sprinkler and its actuation element were electrically wired to establish a closed loop. As a sprinkler actuated, the electrical circuit associated with the sprinkler was broken, resulting in an event signal.

The gas temperature was monitored by thermocouples fabricated from 20-gage (0.8 mm diameter), inconel-sheathed, chromel–alumel thermocouple wires. The thermocouples beads were located 0.17 m (6.5 in.) below the ceiling at selected radial locations from the ignition location.

Radiant heat flux was monitored by a water-cooled, Gardon-type heat flux gage installed 1.2 m (4 ft) from the main array at half the storage height of the main array. The gage was aimed toward and aligned with the transverse flue of the main storage array in which ignition was initiated. For tests in which only a single storage array was used, the gage was installed on a free standing steel frame. Otherwise, the gage was mounted on a steel rack element of the target array at half the height of the main array.

Ignition Source

The ignition source consisted of four igniters, each made of one cotton-batting roll, 76 mm (3 in.) long and 76 mm (3 in.) in diameter, soaked with 0.11-kg (4 oz) gasoline and enclosed in a polyethylene bag.

The cotton-batting rolls were located at the base corners of the bottom four pallet loads at the intersection of the longitudinal flue and the transverse flue at, or near, the center of the main array, as shown in Figures 3, 4, 6, 9 and 11.

Test Procedures

Each fire test was started by applying a propane torch flame to the four igniters.

Data signals were monitored and recorded one scan per second using a data acquisition system. The tests were terminated when the ceiling gas temperature decreased to, and stayed below, 38°C (100°F).

FIRE TEST RESULTS

Evaluation Criteria

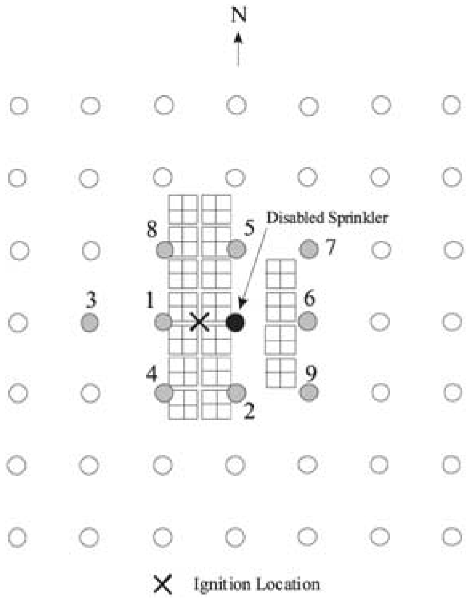
The sprinkler's performance was evaluated based on (1) the number of sprinklers actuated in each test, (2) the steel angle temperature, and (3) the extent of the fire spread and amount of commodity consumed by the fire. Based on the traditional 12-head design for suppression-mode sprinklers, the number of sprinkler actuations should not exceed twelve in any of the five tests. In each of the tests where the sprinklers were allowed to operate normally and were not obstructed, the number of sprinkler actuations should not exceed six [7]. The steel angle temperature should be lower than 538°C (1000°F) to ensure that the protection is adequate to maintain the integrity of building structure. Fire spread through the commodity should be confined to a floor area well within the extent of the tested storage arrays to ensure that the test results are applicable to a much larger array floor area.

Results of Test 1

As mentioned above, this test was conducted to simulate a failure mode of sprinkler operation under a 9.1-m (30 ft) high ceiling for the scenario where the ignition was centered below two sprinklers, of which one sprinkler was intentionally rendered inoperative.

Figure 12 shows the sprinkler operating sequence recorded in the test. A total of nine sprinklers were actuated in this test, fewer than the allowable maximum of twelve sprinklers. The fire was progressively suppressed after the ninth sprinkler was actuated at 9 min and 39 s after ignition.

The maximum steel angle temperature was about 209°C (408°F), which is lower than the limit of 538°C (1000°F).



OPERATING SEQUENCE	TIME (MIN:SEC)
1	0:38
2	0:42
3	0:46
4	0:47
5	0:54
6	1:48
7	2:38
8	6:18
9	9:39

Figure 12. *Actuated sprinklers (colored in gray) in Test 1.*

Figure 13 shows that the fire damage was mainly in the central six storage stacks of the main array. The target array was only scorched on its central west surfaces in the bottom three tiers. The total commodity consumption was about seven pallet loads.

Results of Test 2

Figure 14 shows only two sprinklers, 1.5 m (5 ft) east and 1.5 m (5 ft) west of the ignition location, were actuated to suppress the fire. An infrared image showed that only a few flamelets remained in the bottom two tiers of the main array three minutes into the test.

The maximum steel angle temperature was about 79°C (174°F), much lower than 538°C (1000°F).

Figure 15 shows that the extent of fire damage was limited in the central four stacks of the main storage array. The commodity consumption was estimated to be two pallet loads.

Results of Test 3

Test 3 was conducted to evaluate the effect of a bar joist obstruction on the fire suppression performance when the sprinkler was directly above the fire source under a 9.1-m (30 ft) high ceiling.

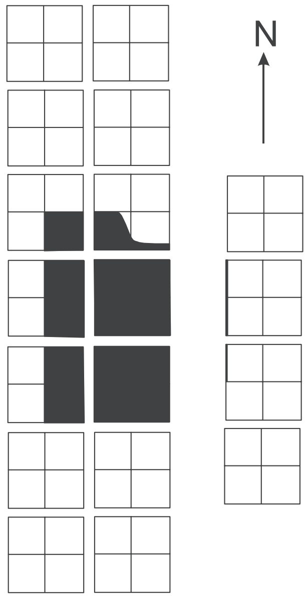
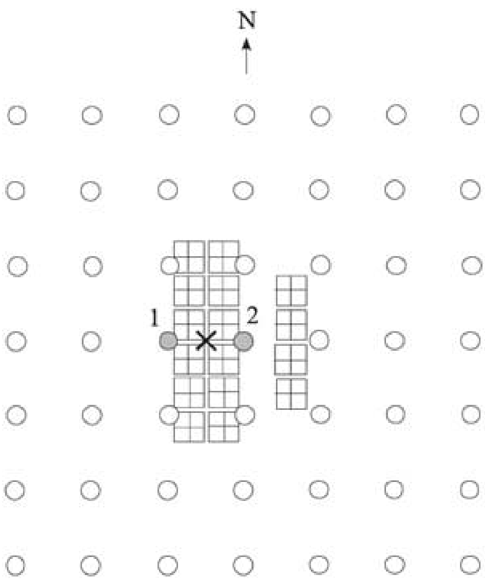


Figure 13. *Extent of fire damage (colored in black) in Test 1.*



OPERATING SEQUENCE	TIME (MIN:SEC)
1	0:39
2	0:45

Figure 14. *Actuated sprinklers (colored in gray) in Test 2.*

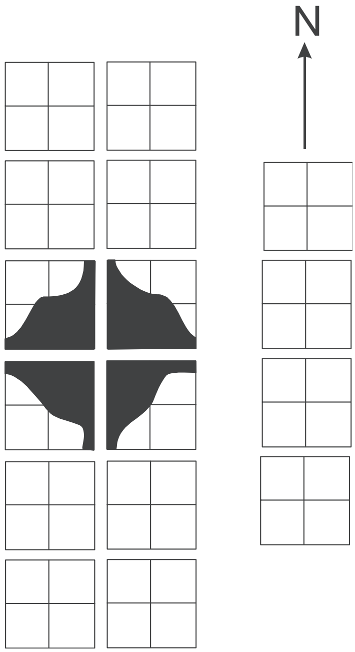


Figure 15. *Extent of fire damage (colored in black) in Test 2.*

Figure 16 shows that only one sprinkler was actuated to suppress the fire in this test.

The maximum recorded steel angle temperature was 32°C (90°F), well below the limit of 538°C (1000°F).

Figure 17 shows the radiant heat flux measured 1.2 m (4 ft) from the storage array. Based on the measured heat fluxes and exposure duration, the fire jump across a 1.2-m (4 ft) wide aisle was deemed unlikely [11].

Figure 18 illustrates the extent of fire damage, which shows that the fire was confined in the central four stacks of the storage array. The total commodity consumption was estimated to be one and one-half pallet loads.

Results of Test 4

Figure 19 shows that only the sprinkler directly above the ignition location was actuated in this test. The fire was quickly suppressed after the sprinkler actuation.

The maximum steel angle temperature was 46°C (115°F), much lower than 538°C (1000°F).

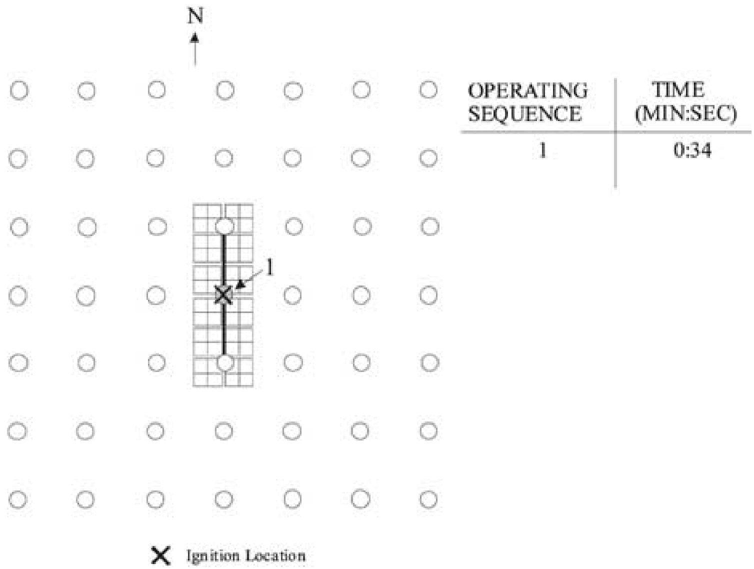


Figure 16. *Actuated sprinklers (colored in gray) in Test 3.*

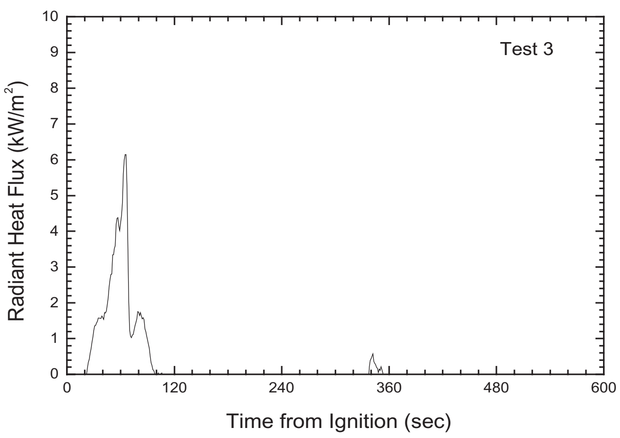


Figure 17. *Radiant heat flux 1.2 m (4 ft) from the storage array measured in Test 3.*

Figure 20 shows the radiant heat flux measured 1.2 m (4 ft) from the storage array. The fire jump across a 1.2-m (4 ft) wide aisle was deemed unlikely due to the low heat flux [11].

Figure 21 exhibits the extent of fire damage. The damage area was mainly confined in the central four stacks of the storage array. The amount of commodity consumption by fire was about three pallet loads.

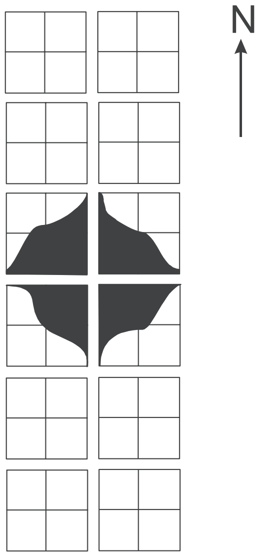
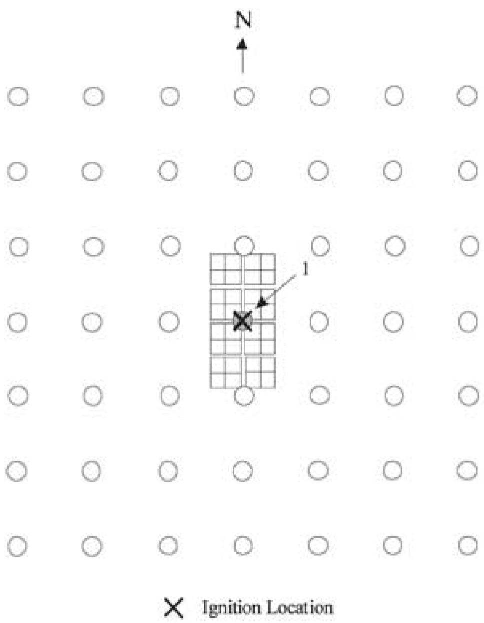


Figure 18. *Extent of fire damage (colored in black) in Test 3.*



OPERATING SEQUENCE	TIME (MIN:SEC)
1	0:17

Figure 19. *Actuated sprinklers (colored in gray) in Test 4.*

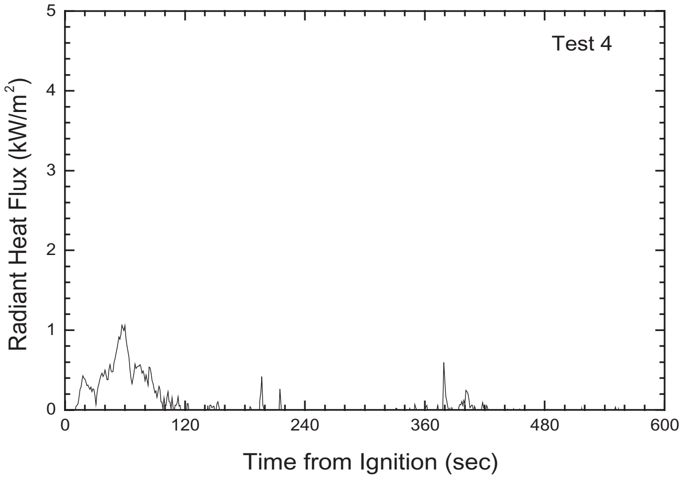


Figure 20. *Radiant heat flux 1.2 m (4 ft) from the storage array measured in Test 4.*

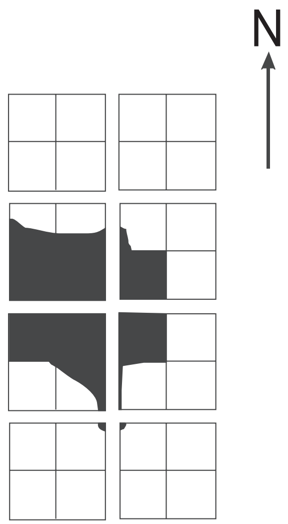
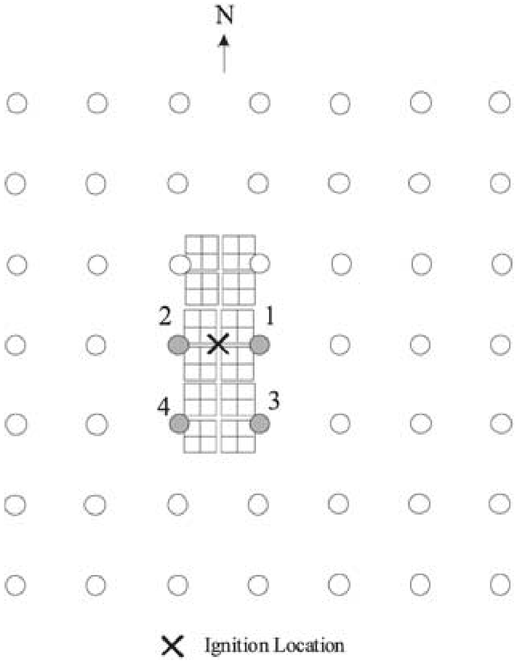


Figure 21. *Extent of fire damage (colored in black) in Test 4.*

Results of Test 5

Figure 22 shows that a total of four sprinklers were actuated in the test. The fire was progressively suppressed in a period of about 6 min after sprinkler actuations.



OPERATING SEQUENCE	TIME (MIN:SEC)
1	0:27
2	0:28
3	0:35
4	0:37

Figure 22. *Actuated sprinklers (colored in gray) in Test 5.*

The maximum steel angle temperature was 62°C (144°F), lower than the limit of 538°C (1000°F).

Figure 23 shows the radiant heat flux measured 1.2 m (4 ft) from the storage array. The heat flux gage did not function properly in the period from about 20 to 400 s after ignition. However, based on the comparison between the fire size observed in this test and those observed in other tests and the low heat flux measured after 400 s after ignition in this test, the fire jump across a 1.2-m (4 ft) wide aisle was deemed unlikely [11].

Figure 24 exhibits the extent of fire damage in Test 5. The damage area was mainly confined in the central four stacks of the storage array. The amount of commodity consumed by fire was about four pallet loads.

SUMMARY AND CONCLUSION

The fire suppression performance of a prototype, K-16.8, suppression-mode, upright sprinkler was evaluated under a 9.1-m (30 ft) high ceiling and a 10.7-m (35 ft) high ceiling with large-scale fire tests. The sprinkler is intended to provide fire suppression performance under 9.1-m (30 ft) high ceilings for fire challenges up to expanded Group A plastic

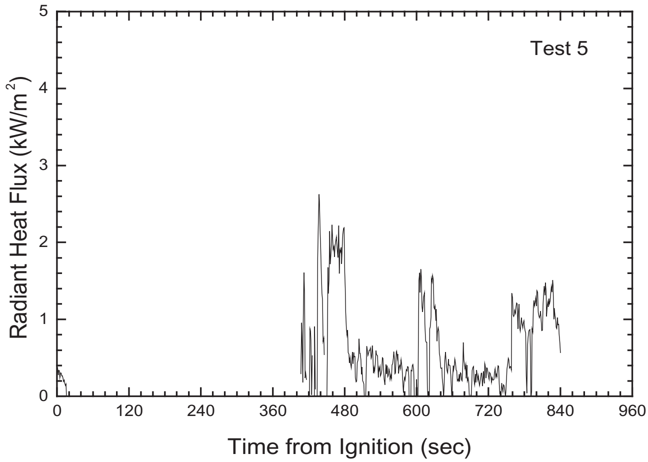


Figure 23. *Radiant heat flux 1.2 m (4 ft) from the storage array measured in Test 5.*

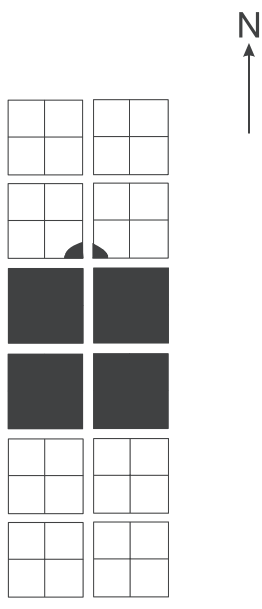


Figure 24. *Extent of fire damage (colored in black) in Test 5.*

commodities in cartons; under 10.7-m (35 ft) high ceilings, the intended fire challenges are up to unexpanded, Group A plastic commodities in cartons. The sprinkler was equipped with a fusible link having a Response-Time-Index (RTI) value of 25 $(m\,s)^{1/2}$ (45 $(ft\,s)^{1/2}$) and a temperature rating

Table 1. A summary of test conditions and key results.

Test Conditions		Test 1	Test 2	Test 3	Test 4	Test 5
Storage size (Pallet loads)	Main Array	$2 \times 7 \times 5$ 2high	$2 \times 6 \times 5$ high	$2 \times 6 \times 4$ high	$2 \times 4 \times 5$ high	$2 \times 6 \times 6$ high
	Target Array	$1 \times 4 \times 5$ high	$1 \times 4 \times 5$ high	N.A.	N.A.	N.A.
Ceiling height (m)		9.1	9.1	9.1	10.7	10.7
Storage height (m)		7.5	7.5	5.9	7.5	9.0
Aisle width (m)		1.2	1.2	N.A.	N.A.	N.A.
Ignition centered below (No. of sprinklers)		2 (one plugged)	2	1	1	2
Sprinkler temperature rating (°C)		74	74	74	74	74
Sprinkler RTI $(m\,s)^{1/2}$		25	25	25	25	25
Sprinkler spacing ($m \times m$)		3.1×3.1	3.1×3.1	3.1×3.1	3.1×3.1	3.1×3.1
Sprinkler operating pressure (kPa)		241	241	241	345	345
Results						
No. of sprinklers actuated		9	2	1	1	4
Peak steel angle temperature (°C)		209	79	32	46	62
Maximum one-min average steel angle temperature (°C)		208	66	31	45	59
No. of pallet loads consumed		7	2	1.5	3	4

N.A. – Not Applicable.

of 74°C (165°F). The sprinkler spacing was 3.1 m by 3.1 m (10 × 10 ft) in the tests. The designated sprinkler operating pressure was 241 kPa (35 psig) for 9.1-m (30 ft) high ceilings, and 345 kPa (50 psig) for 10.7-m (35 ft) high ceilings. The pipe shadow of schedule-40, 2.5-in. sprinkler pipes (with 73-mm OD) was simulated in the large-scale fire tests. The test conditions and key results are summarized in Table 1.

Three fire tests were conducted under a 9.1-m (30 ft) high ceiling and two were conducted under a 10.7-m (35 ft) ceiling. When the sprinklers were allowed to operate normally, the tests demonstrated that the upright sprinkler could provide fire suppression performance for the above-intended fire challenges under both the 9.1-m (30 ft) and 10.7-m (35 ft) high ceilings. The sprinkler also demonstrated adequate fire suppression performance for expanded meat trays in cartons under the 9.1-m (30 ft) high ceiling when obstructed by a bar joist with a 100-mm (4 in.) wide chord. In the test where a failure mode of sprinkler operation was simulated, the sprinkler provided fire-control performance with nine operating sprinklers, fewer than the limit of twelve operating sprinklers typically required for suppression-mode sprinklers.

Based on the five large-scale fire tests conducted in this program, the tested prototype upright sprinkler provided fire protection performance expected from suppression-mode sprinklers.

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