# USE OF K360 SUPPRESSION-MODE SPRINKLERS FOR PROTECTION OF HIGH CEILING OCCUPANCIES

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## ABSTRACT

Large-scale fire tests were conducted to evaluate K-factor* 360 (K25.2), suppression-mode sprinkler protection for exposed, expanded plastics stored in buildings with ceiling heights up to 18.3 m (60 ft). Six tests evaluated the effect of large ceiling clearance, i.e., a wide separation from the top of a fuel array to the ceiling. These tests used 4.6 m (15 ft) high rack storage arrangements of HDPE plastic pallets under 13.7 m (45 ft), 15.2 m (50 ft), 16.7 m (55 ft) and 18.3 m (60 ft) ceilings. Four tests evaluated the effectiveness of K360 suppression-mode sprinkler protection under 12.2 m (40 ft) and 13.7 m (45 ft) ceilings using the standard FM Global suppression-mode sprinkler evaluation fire test protocol. Test results are presented.

**KEYWORDS:** Sprinklers, Sprinkler protection, K360 suppression-mode sprinklers, K25.2 suppression-mode sprinklers, Large-scale fire testing, High ceilings

## BACKGROUND AND INTRODUCTION

Suppression-mode sprinklers were developed at FM Global Research during the mid-1980's as a part of a comprehensive fire sprinkler research program[1] which sought to design effective fire protection for high-hazard industrial/commercial occupancies. The sprinklers developed in this program combined a quick responding sprinkler actuation mechanism with high-volume water discharge. These sprinklers depended upon a specialized water distribution pattern in terms of sprinkler coverage and sprinkler droplet thrust force which enabled them to effectively deliver a high water density to penetrate the strong buoyant fire plumes generated by high-challenge fires.

The first suppression-mode sprinklers used K200 (K14.0) discharge nozzles with quick-response actuation mechanisms having nominal RTI† of 28 $m^{½}$-$s^{½}$ (50 $ft^{½}$-$s^{½}$). These sprinklers provided fire suppression for a variety of commodities, from paper and wood products up to plastics in corrugated cartons. Even more significant was that these sprinklers would allow ceiling-only sprinkler protection for building with ceiling heights up to 12.2 m (40 ft) at system pressures of 3.4 and 5.2 bar (50 and 75 psi).

By the mid-1990's a second-generation of suppression-mode sprinkler had been developed. These sprinklers used a higher-capacity nozzle (K360 [25.2]) together with the same quick-response actuation mechanism. The K360 sprinkler provided the same fire suppression performance at reduced pressures and was designed for application to 13.7 m and 15.2 m (45 ft and 50 ft) high buildings at system pressures of 3.4 and 4.1 bar (50 and 60 psi).

The comprehensive testing of first- and second-generation suppression-mode sprinklers allowed development of a test protocol[2] that could evaluate the adequacy of these sprinklers for a given commodity and building height using two large-scale rack storage fire tests and water distribution

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* The K-factor is a number incorporating the sprinkler nozzle discharge coefficient that indicates discharge capacity. It is defined as $K=Q/p^{½}$, where Q is the water discharge rate and p is the discharge pressure. Given in units of liters/minute/$bar^{½}$ (gpm/$psi^{½}$).
† Response Time Index – provides a relative measure of sprinkler sensitivity. Under identical situations, sprinklers with relative low RTI will actuate faster than those with high values. Given in units of $(m\text{-}s)^{½}$($[ft\text{-}s]^{½}$)


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measurements. The large-scale fire tests required for evaluation of suppression-mode sprinklers for a given commodity and building height consisted of the following two scenarios: (a) low-storage-height arrangement with the main array* centered directly below one sprinkler (called an Under 1 test), and (b) high-storage-height arrangement with the main array centered below two sprinklers (a Below 2 test). These two tests were found to be quite effective in determining the fire suppression capability of suppression-mode sprinklers for the majority of proposed applications. The Under 1 test scenario evaluated the ability of the sprinkler to penetrate a fire plume and deliver water to the base of the fire; the Between 2 test evaluated the sprinkler's ability to disperse water over its entire design coverage area. This two-test protocol was used to confirm suppression-mode sprinkler applications for various commodities under ceilings up to 13.7 m (45 ft) high.

Because of the high-volume water discharge requirements of suppression-mode sprinklers, one criterion necessary for application is a water supply design requirement of no more than twelve operating sprinklers. To provide a safety factor, it was determined that fire suppression under the two-test protocol must be achieved using no more than eight operating sprinklers. This allows a 50 percent safety factor for the twelve sprinkler design requirement.

Eventually there was demand for protection of buildings with ceilings higher than 13.7 m (45 ft) and even more hazardous commodities. Of interest were the protection of buildings with ceiling heights up to 18.3 m (60 ft) and high-challenge commodities such as exposed, expanded and unexpanded plastics. Another concern with high ceilings was that the performance of suppression-mode sprinklers might degrade as ceiling clearances, i.e., the open space from the top of protected commodities to the ceiling, increased along with ceiling heights. It was unclear if large ceiling clearances would require modification of the two-test sprinkler evaluation protocol.

The objectives of these large-scale fire tests[3] were to evaluate the performance of the K360 (K25.2) suppression-mode sprinkler at ceiling heights of 12.2 m (40 ft) and higher, and to investigate the effect of large ceiling clearance with ceiling heights up to 18.3 m (60 ft).

## TEST PROCEDURES

Tests were conducted under a 24 m x 24 m (80 ft x 80 ft) height-adjustable ceiling at the FM Global Research Large Burn Laboratory located in West Glocester, RI, USA. The ceiling can be positioned at continuous vertical heights up to 18.3 m (60 ft). Tests were performed under ventilated conditions. Fresh air was drawn into the test volume through a bank of adjustable louvers on one wall of the facility. Air passing through the test zone was collected via a duct system at the ceiling and discharged through an air pollution abatement system. For these tests, a volumetric evacuation rate of 94,400 L/s (200,000 cfm) for the Large Burn Laboratory was used. Rack storage arrangements were used in these tests because they have proven to be the most challenging for industrial/commercial occupancies. A summary of test parameters is provided in Tables 1 and 2.

To investigate the influence of high ceiling clearance, several tests were conducted using 4.6 m (15 ft) storage arrangements under 13.7 m (45 ft), 15.2 m (50 ft), 16.8 m (55 ft) and 18.3 m (60 ft) ceilings with the storage array centered below one ceiling sprinkler (Tests 1 to 6, Table 1). Fig. 1 shows the test arrangement for 4.6 m (15 ft)-high storage under a 13.7 (45 ft) ceiling.

The two-test protocol was followed for final determination of application of the K360 suppression-mode sprinklers to exposed, unexpanded plastic under high ceilings. The two-test protocol for 12.2 m (40 ft) building applications consists of a 7.6 m (25 ft) high storage arrangement with the main array centered directly below one ceiling sprinkler and a 10.7 (35 ft) high storage with the main array centered below two sprinklers. For 13.7 m (45 ft) building applications, the test protocol consists of a

* The main array contains ignition.

10.7 m (35 ft) high storage with the main array centered directly below one sprinkler and a 12.2 m (40 ft) high storage with the main array centered below two sprinklers (Tests 7 to 10, Table 2).

**TABLE 1.** Summary – Test parameters (Tests 1 to 6)

| **TEST NUMBER** | **1** | **2** | **3** | **4** | **5** | **6** |
|---|---|---|---|---|---|---|
| **COMMODITY** | PP | PP | PP | PP | PP | PP |
| **STORAGE HEIGHT [m (ft)]** | 4.6 (15) | 4.6 (15) | 4.6 (15) | 4.6 (15) | 4.6 (15) | 4.6 (15) |
| **CEILING HEIGHT [m (ft)]** | 13.7 (45) | 18.3 (60) | 18.3 (60) | 15.2 (50) | 16.8 (55) | 15.2 (50) |
| **SYSTEM PRESSURE [bar (psi)]** | 3.4 (50) | 3.4 (50) | 5.2 (75) | 3.4 (50) | 3.4 (50) | 3.4 (50) |
| **SYSTEM FLOW [l/m (gpm)] *** | 674 (178) | 674 (178) | 825 (218) | 674 (178) | 674 (178) | 674 (178) |
| **IGNITION BELOW (NO. SPRINKLERS)** | One | One | One | One | One | One |

**TABLE 2.** Summary – Test parameters (Tests 7 to 10)

| **TEST NUMBER** | **7** | **8** | **9** | **10** |
|---|---|---|---|---|
| **COMMODITY** | PP | PP | PP | PP |
| **STORAGE HEIGHT [m (ft)]** | 12.2 (40) | 12.2 (40) | 10.7 (35) | 7.6 (25) |
| **CEILING HEIGHT [m (ft)]** | 13.7 (45) | 13.7 (45) | 12.2 (40) | 12.2 (40) |
| **SYSTEM PRESSURE [bar (psi)]** | 3.4 (50) | 4.1 (60) | 4.1 (60) | 4.1 (60) |
| **SYSTEM FLOW [l/m (gpm)] *** | 674 (178) | 738 (195) | 738 (195) | 738 (195) |
| **IGNITION BELOW (NO. SPRINKLERS)** | Two | Two | Two | One |

*Flow rate for each operating sprinkler. DRR- Double-Row Racks; PP – High Density Polyethylene Plastic Pallets.

### High Ceiling Clearance Fire Tests

Six large-scale fire tests were conducted to evaluate the effects of large ceiling clearance. Test variables included ceiling height and sprinkler system discharge pressure. The main array, i.e., the array containing the ignition source, was centered directly below a ceiling sprinkler with the ignition location offset 0.61 m (2 ft) from center within the central transverse flue (Fig. 1).

Test 1 was conducted using a 13.7 m (45 ft) ceiling height and a system discharge pressure of 3.4 bar (50 psi). In Tests 2 and 3 the ceiling height was set at 18.3 m (60 ft) with system pressures of 3.4 bar and 5.2 bar (50 and 75 psi), respectively. Tests 4, 5 and 6 used a system pressure of 3.4 bar (50 psi) at ceiling heights of either 15.2 m (50 ft) or 16.8 m (55 ft).

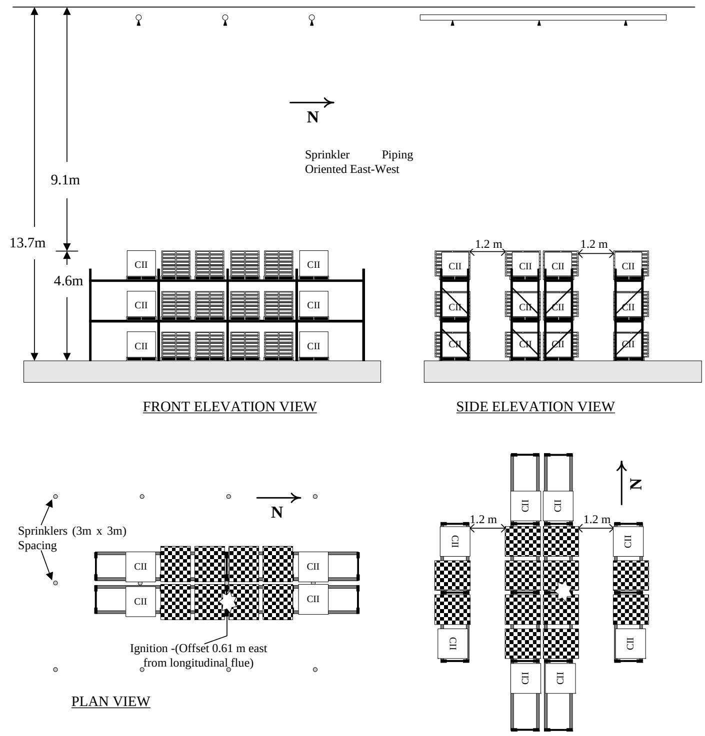


**FIGURE 1.** Test arrangement – High ceiling clearance fire tests (13.7 m ceiling)

## Suppression-Mode Sprinkler Evaluation Fire Tests

The suppression-mode sprinkler validation protocol uses two large-scale fire tests: a high-storage-height, small-ceiling-clearance scenario; and a low-storage-height, large-ceiling-clearance scenario to make the definitive assessment for application of these sprinklers to a given ceiling height and commodity. The test protocol began at 13.7 m (45 ft) for this application (Fig. 2) was completed at 12.2 m (40 ft).

## Test Fuels

High density polyethylene (HDPE) plastic pallets were used to represent the category of exposed, unexpanded plastic commodity in all of the tests conducted. The pallets were 1.0 m x 1.2 m x 14 mm (40 in. x 48 in. x 5-9/16 in.) four-way type, manufactured using non-fire-retarded plastic.* The top surface was gridded, with numerous circular and rectangular openings representing approximately 20 percent of the total surface area. The bottom deck had four large openings in each quadrant plus small rectangular openings which, when combined, represented 48 percent of the total surface area of the pallet underside. The pallets weighed an average of 25.8 kg (57 lbs.) each. Seven plastic pallets were stacked on top of a 1.07 m x 1.07 m x 127 mm (42 in. x 42 in. x 5 in.) two-way, slatted deck, hardwood pallet to represent one pallet-load of commodity.

* Oxygen bomb calorimetry indicated a heat content of 44,400 joules/gram (19,100 BTU/lb) with 0.13 percent inert material.

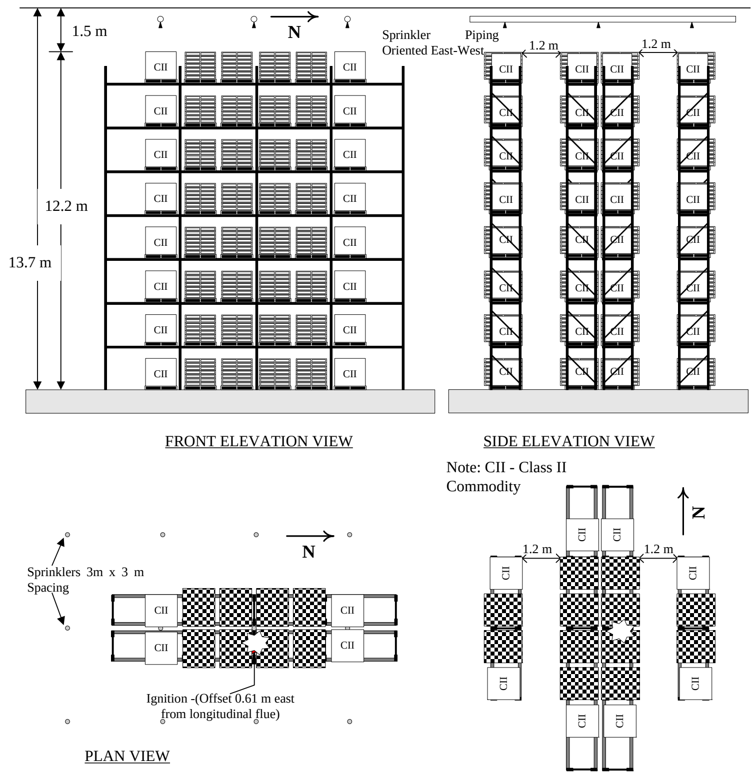


**FIGURE 2.** Test arrangement – Suppression-mode sprinkler evaluation fire tests (13.7 m ceiling)

## Test Instrumentation

Instrumentation was used to monitor the fires and allow assessment of sprinkler system performance. Included were thermocouples to monitor gas temperatures at the ceiling over the test area; bi-directional differential flow probes for measuring near-ceiling gas velocities over the ignition zone; and electrical circuits wired through the sprinkler actuation mechanisms to determine sprinkler actuation times.

To determine the potential for thermal damage to structural roof supports, 1.2 m (4 ft) sections of 51 mm x 51 mm (2 in. x 2 in.) steel angle were attached to the ceiling directly over the center of the main fuel array in all tests. The temperatures of the angles were monitored by thermocouple beads embedded into the metal.

## Sprinkler Protection

A FM Approved,* pendent-type, suppression-mode sprinkler with nominal 25 mm (1 in.) diameter orifice and 74 $^oC$ (165 $^oF$) temperature rating was used in all tests. The actuation mechanism was rated at a nominal RTI† of 28 $m^{1/2}$-$s^{1/2}$ (50 $ft^{1/2}$-$s^{1/2}$) and the sprinkler nozzle had a K-factor‡ of 360 L/m/$bar^{½}$ (25.2 gpm/$psi^{1/2}$).

The sprinklers were installed under the 24 m x 24 m (80 ft x 80 ft) smooth, flat horizontal ceiling on 3 m x 3 m (10 ft x 10 ft) spacing with the deflectors located 457 mm (18 in.) down from the ceiling surface. Sprinkler branchlines were nominal 2-1/2 in. diameter steel pipe. The water supply was set to

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† Response Time Index (RTI) is a quantitative measure of sprinkler link sensitivity. Under identical operating conditions, sprinklers with low RTI values are expected to actuate faster than those with higher RTI values.

‡ The K-factor is a number indicating sprinkler nozzle discharge capacity. It is defined as $K=Q/p^{½}$ where Q is the water discharge rate and p is the sprinkler nozzle discharge pressure.

provide a constant discharge pressure independent of the number of operating sprinklers. The system pressure was set according to the fire test scenario and maintained at this value for the duration of the test.

### Ignition Procedure

Ignition was accomplished using two pilot igniters* placed at the bottom pallets on either side of the central transverse flue of the main array (Figs. 1 and 2). The igniters were placed 0.61 m (2 ft) from the centerline of the longitudinal flue of the main array. These were lighted using a propane torch to begin each test.

## TEST RESULTS

Instrumentation, photographic documentation and observations from trained observers were used to assess the effectiveness of the K360 suppression-mode sprinklers. Of primary interest were: (1) the total number of sprinkler operations occurring during test, (2) near-ceiling gas and ceiling steel temperatures, and (3) the extent of fire damage to the fuel arrays. Test data summaries are presented in Tables 3, 4 and 5.

The total number of sprinkler operations is used to evaluate the effectiveness of a sprinkler system. Suppression-mode sprinklers are designed to suppress fires quickly with relatively few sprinkler operations. Water supplies for these sprinklers are typically designed to accommodate twelve operating sprinklers. Because of the necessity to maintain a 50 percent safety factor, no more than eight operating sprinklers are allowed during evaluation tests.

Near-ceiling gas and steel temperatures are monitored to evaluate the ability of sprinklers to successfully cool the fire zone and reduce the potential for roof involvement and collapse. Most structural steel alloys begin to soften when the metal reaches 538 $^{o}$C (1000 $^{o}$F). Actual failure depends upon the alloy, loading, thickness and unsupported length. For these tests, a steel temperature of 538 $^{o}$C (1000 $^{o}$F) was used as a failure criterion.

The fuel arrays used in large-scale storage fire tests are designed to replicate a representative section of warehouse storage. This usually consists of a main array, in which ignition is placed, and one or two target arrays separated by an aisle space. If fire damage is not confined within main and target arrays and reaches the ends or outside faces, the assumption is that the fire would not be controlled and the entire warehouse would have become involved in fire. For these tests, successful fire suppression requires that fire damage not extend to the longitudinal ends of main and target arrays or to the outermost faces of target arrays (transverse direction).

### High Ceiling Clearance Fire Test Results

Six large-scale fire tests were conducted to determine if very large ceiling clearances pose a greater fire hazard for K360 suppression-mode sprinklers than either the low-storage height, large ceiling clearance test or the high-storage height, reduced ceiling clearance test used for large-scale fire test evaluation of suppression-mode sprinklers. Tests 1 to 6 used 4.6 m (15 ft) high rack storage of plastic pallets.

One concern was the possible development of a stronger fire plume (i.e., increased plume temperature and velocity) above the top of the array for a low-storage-height/large-ceiling- clearance test scenario. Measurements of near-ceiling gas temperature and velocities just prior to first sprinkler actuation were examined.

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* A pilot igniter is a 152 mm-long by 76 mm-diameter (6 in. x 3 in.) cellucotton roll soaked with 236 ml (8 fluid ounces) of gasoline and sealed in a clear polyethylene plastic bag.

Fig. 3 presents near-ceiling gas temperatures measured directly over the array center for the tests conducted. The near-ceiling temperatures directly over the array center ranged from 108 $^{o}$C (226 $^{o}$F) in Test 5 (16.8 m [55 ft] ceiling) to 125 $^{o}$C (257 $^{o}$F) in Test 1 (13.7 m [45 ft] ceiling) at the time of first sprinkler actuation. Although the near-ceiling temperature at the 13.7 m (45 ft) ceiling height (Test 1) was slightly higher, there was no significant difference in the near-ceiling gas temperatures at first sprinkler actuation as ceiling heights increased (Tests 2 to 6).

**TABLE 3.** Fire test summary – Tests 1 to 4

| TEST IDENTIFICATION | TEST 1 | TEST 2 | TEST 3 | TEST 4 |
|---|---|---|---|---|
| STORAGE/CEILING HEIGHT [ m/m (ft/ft)] | 4.6/13.7 (15/45) | 4.6/18.3 (15/60) | 4.6/18.3 (15/60) | 4.6/15.2 (15/50) |
| ARRAY SIZE* MAIN (TARGET) | 2Dx6Lx3H (1Dx4Lx3H) | 2Dx6Lx3H (1Dx4Lx3H) | 2Dx6Lx3H (1Dx4Lx3H) | 2Dx6Lx3H (1Dx4Lx3H) |
| IGNITION BELOW | 1 | 1 | 1 | 1 |
| SYSTEM PRESSURE [bar (psi)] | 3.4 (50) | 3.4 (50) | 5.2 (75) | 3.4 (50) |
| RESULTS | | | | |
| FIRST SPRINKLER [min:s] | 4:22 | 4:55 | 4:42 | 4:24 |
| LAST SPRINKLER [min:s] | 4:22 | 7:25 | 6:38 | 4:24 |
| TOTAL SPRINKLERS | 1 | 33 | 23 | 1 |
| AVG DISCHARGE** [liter/min (gpm)] | | | 674 (178) | 674 (178) |
| PEAK/MAX. AVG. CEILING TEMP. [$^{o}$C ($^{o}$F)] | 124/72 (255/162) | 321/86 (610/187) | 321/170 (610/338) | 121/66 (250/151) |
| PEAK/MAX. AVG. STEEL TEMP. [$^{o}$C ($^{o}$F)] | 26/25 (79/77) | 52/51 (126/124) | 52/52 (126/126) | 24/24 (75/75) |
| PEAK/MAX.AVG 1.5 m (5 ft) RADIUS VEL. [m/s (ft/s)] | 9.8/3.2 (32/10.5) | 14.1/5.6 (46.2/18.4) | 14.1 /7.7 (46.2/25.3) | 6.7 /4.5 (22/14.8) |
| TIME TO TARGET IGNITION [min:s] | DNI | 6:35 | 5:48 | DNI |
| TEST DURATION [min:s] | 10:00 | 13:00 | 12:00 | 7:30 |
| DNI – Did Not Ignite. *Pallet-loads **Average Sprinkler Discharge | | | | |

**TABLE 4.** Fire test summary – Tests 5 & 6

| TEST IDENTIFICATION: | TEST 5 | TEST 6 |
|---|---|---|
| STORAGE/CEILING HEIGHT [ m/m (ft/ft)] | 4.6/16.8 (15/55) | 4.6/15.2 (15/50) |
| ARRAY SIZE* MAIN (TARGET) | 2D x 6L x 3H (1D x 4L x 3H) | 2D x 6L x 3H (1D x 4L x 3H) |
| IGNITION BELOW | 1 | 1 |
| SYSTEM PRESSURE [bar (psi)] | 3.4 (50) | 3.4 (50) |
| RESULTS | | |
| FIRST SPRINKLER [min:s] | 4:33 | 4:43 |
| LAST SPRINKLER [min:s] | 7:05 | 4:43 |
| TOTAL SPRINKLERS | 46 | 1 |
| AVG DISCHARGE** [liter/min (gpm)] | 674 (178) | 674 (178) |
| PEAK/MAX. AVG. CEILING TEMP. [$^{o}$C ($^{o}$F)] | 390/181 (734/358) | 110/63 (230/145) |
| PEAK/MAX. AVG. STEEL TEMP. [$^{o}$C ($^{o}$F)] | 52/50 (126/122) | 22/22 (72/72) |
| PEAK/MAX.AVG 1.5 m (5 ft) RADIUS VEL. [m/s (ft/s)] | 8.9/5.8 (29.2/19.0) | 6.5/4.5 (21.3/14.8) |
| TIME TO TARGET IGNITION [min:s] | Not Determined | DNI |
| TEST DURATION [min:s] | 7:00 | 8:00 |
| DNI - Did Not Ignite *Pallet-loads **Average Sprinkler Discharge | | |

**TABLE 5.** Fire test summary – Tests 7 to 10

| TEST IDENTIFICATION: | TEST 7 | TEST 8 | TEST 9 | TEST 10 |
|---|---|---|---|---|
| STORAGE/CEILING HEIGHT [ m/m (ft/ft)] | 12.2/13.7(40/45) | 12.2/13.7(40/45) | 10.7/12.2(35/40) | 7.6/12.2(25/40) |
| ARRAY SIZE* MAIN (TARGET) | 2D x 6L x 8H (1Dx 4L*x 8H) | 2D x 6L x 8H (1Dx 4Lx 8H) | 2D x 6L x 7H (1Dx 4Lx 7H) | 2D x 6L x 5H (1Dx 4Lx 5H) |
| IGNITION BELOW | 2 | 2 | 2 | 1 |
| SYSTEM PRESSURE [bar (psi)] | 3.4 (50) | 4.1 (60) | 4.1 (60) | 4.1 (60) |
| | | | | |
| FIRST SPRINKLER [min:s] | 4:48 | 5:30 | 6:38 | 4:33 |
| LAST SPRINKLER [min:s] | 8:49 | 16:20 | 9:01 | 4:33 |
| TOTAL SPRINKLERS | 3** | 4 | 8 | 1 |
| AVG DISCHARGE*** [liter/min (gpm)] | 674 (178) | 738 (195) | 738 (195) | 738 (195) |
| PEAK/MAX. AVG. CEILING TEMP. [$^o$C ($^o$F)] | 183/122 (361/252) | 271/143 (520/289) | 267/164 (512/327) | 126/59 (259/138) |
| PEAK/MAX. AVG. STEEL TEMP. [$^o$C ($^o$F)] | 60/59 (140/138) | 62/61 (144/142) | 56/54 (133/129) | 25/24 (77/75) |
| PEAK/MAX.AVG 1.5 m (5 ft) RADIUS VEL. [m/s (ft/s)] | 6.9/4.6 (22.6/15.1) | 9.5/6.3 (31.2/20.7) | 13.8/7.1 (45.3/23.3) | 5.0/2.3 (16.4/7.5) |
| TIME OF AISLE JUMP [min:s] | DNJ | DNJ | DNJ | DNJ |
| TEST DURATION [min:s] | 16:00 | 20:00 | 25:00 | 16:00 |
| DNJ - Did Not Jump Aisle<br>*Pallet-loads ** Test terminated when fire progressed into the Class II commodity at the ends of the main array. Class II Commodity is double triwall, 1.1 m [42 in.]-cube corrugated carton with sheet metal liner that was used at ends of these arrays. ***Average Sprinkler Discharge | | | | |

Near ceiling gas velocities measured at 1.5 m (5 ft) from directly over the centers of the arrays (Figs. 4 and 5) [*] indicate maximum value at first sprinkler actuation occurring for the 13.7 m (45 ft) ceiling height (Test 1). At ceiling heights of 15.2, 16.8 and 18.3 m (50, 55 and 60 ft), there were no significant differences in the near-ceiling gas velocities at the time of first sprinkler actuation. Fig. 4 shows velocities 1.5 m (5 ft) east of the array center for the time interval between 60 s and 360 s for the first six tests. Sprinkler actuations for Test 1 through Test 6 occurred between 262 s (Test 1) and 295 s (Test 2). Sprinkler actuation is indicated by a sudden drop in velocity as the sprinkler entrains the ceiling gas flow downward. The velocity traces for the 1.5 m (5 ft) east measurement show near-ceiling gas velocities in the range of 4.5 m/s to 5 m/s at the time of first sprinkler actuation in Test 1 (13.7 m [45 ft] ceiling height) which showed the highest recorded velocity. Velocities at this location for the remaining tests range from 1.5 m/s (5 ft/s) in Test 5 (16.8 m [55 ft] ceiling height) to approximately 3 m/s (10 ft/s) in Test 2 (18.3 m [60 ft] ceiling height). Since ignition is offset 0.6 m (2 ft) east in these tests, the velocity measurement at 1.5 m (5 ft) east is closer to the fire plume. The east velocity measurement therefore displays significant flow reversals after first sprinkler actuation.

[*] A 10 s moving average is used for Tests 3, 4, 5, and 6. The 20 s moving average was used for Test 1 and 2 because of a higher data acquisition scanning rate. The effect is a smoothing of the data.

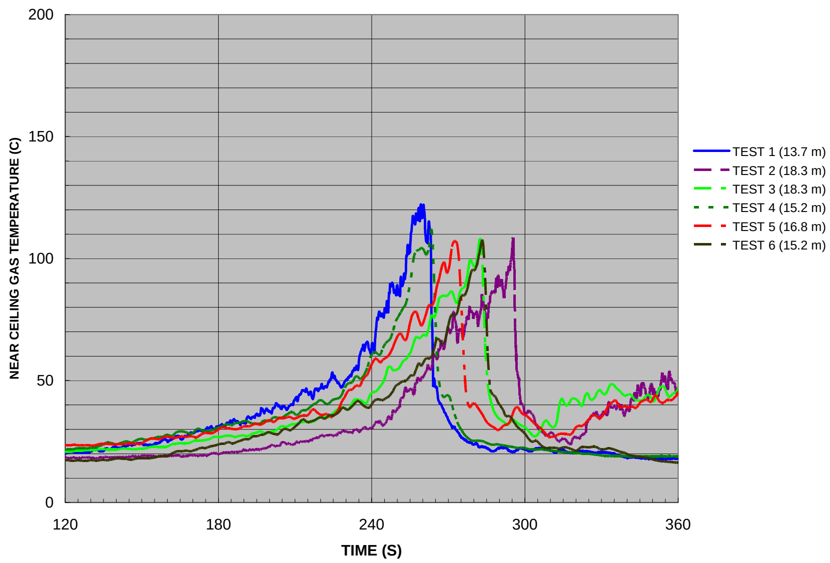


**FIGURE 3.** Near-ceiling gas temperatures over array center (Tests 1 to 6)
(Data presented using 20-s moving average for Tests 1 and 2; 10-s moving average used for Tests 3 to 6.)

Near-ceiling gas velocities were slightly higher at the 1.5 m (5 ft) west locations (Fig. 5). The highest velocity occurred for the 13.7 m (45 ft) ceiling height (Test 1). There was a 5.5 m/s gas flow just before first sprinkler actuation in Test 1. Near-ceiling gas velocities ranged from approximately 2.8 m/s (9 ft/s) in Test 6 (15.2 m [50 ft] ceiling height) to nearly 4 m/s (13 ft/s) in Test 2 (18.3 m [60 ft] ceiling height).

## Suppression-Mode Sprinkler Evaluation Fire Test Results

Tests 7 to 10 were designed to determine the ceiling height limit for the protection of exposed, unexpanded plastics using the two-test suppression-mode sprinkler evaluation protocol.

Based upon previous testing, a ceiling height of 13.7 m (45 ft) using a system pressure of 3.4 bar (50 psi) was selected for the test. Test 7 involved a 12.2 m (40 ft)-high rack storage of HDPE plastic pallets with the main array centered below two ceiling sprinklers. In this test, the fire reached the south (longitudinal) end of the main array and ignited pallet-loads of a Class II (C II) commodity* used to extend main and target arrays. Three sprinklers were operating by the time the test was terminated at 16 minutes after ignition. The test was considered inconclusive since there is no way to extrapolate fire behavior of Class II commodity to plastic pallets. Test 8 was a repeat of Test 7 with increased system pressure (4.1 bar [60 psi]). The arrays were also changed so that they were comprised entirely of plastic pallets rather than using Class II commodity. However, similar to Test 7, fire traveled to the south end of the main array and four sprinklers were operating when the test was terminated at 16 min 40 s after ignition. The fire was not suppressed.

The results from Test 7 and 8 showed that the K360 Suppression-Mode sprinkler, at system pressures up to 4.1 bar (60 psi), could not quickly suppress rack storage of exposed, unexpanded plastics stored to 12.2 m (40 ft) -high in 13.7 m (45 ft)-high buildings. The apparent difficulty was the inability of the sprinkler to extinguish the fire in the first and second tiers as the fire was shielded by the upper tiers of the rack storage arrangement.

* 1.07 m (42 in.)-cube double-walled corrugated carton with metal liner.

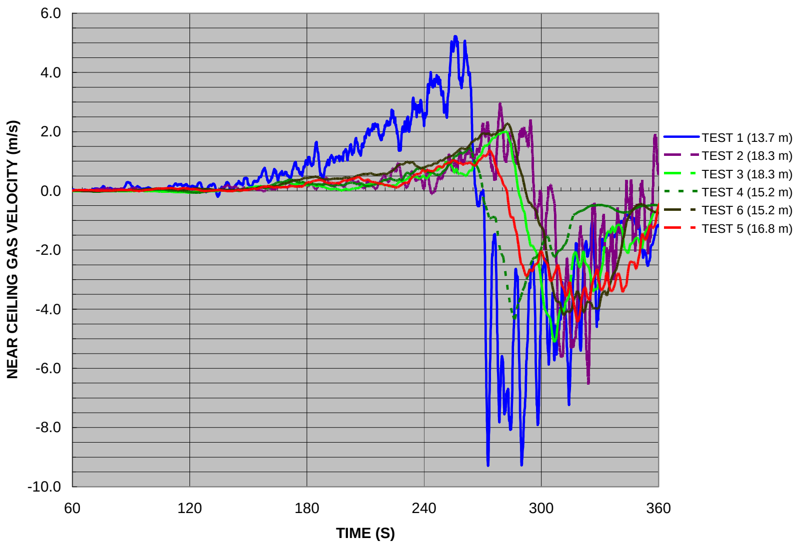


**FIGURE 4.** Near ceiling gas velocities at 1.5 m east of array center (Tests 1 to 6)

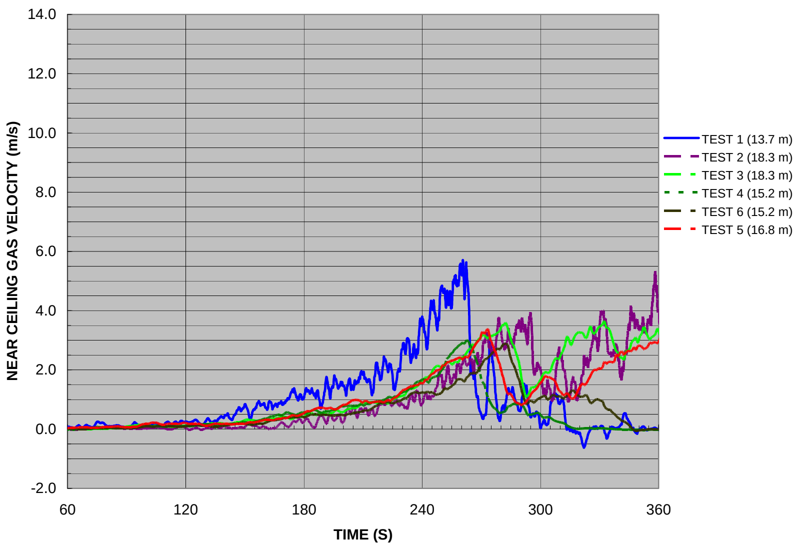


**FIGURE 5.** Near ceiling gas velocities at 1.5 m west of array center (Test 1 to 6)

Test 9 was conducted to determine if quick fire suppression could be achieved in 12.2 m (40 ft) high buildings at a system pressure of 4.1 bar (60 psi). The maximum allowed storage height of 10.7 m (35 ft) was used. The first sprinkler actuated at 4 min 38 s but did not suppress the fire. The second sprinkler actuation occurred at 7 min 26 s after ignition. Eight sprinklers operated during this test. Fig. 6 presents near ceiling gas temperatures for Test 7, Test 8 and Test 9. These data show that ceiling temperatures were increasing in Tests 7 and Test 8 at the time that the tests were terminated, indicating that the fires were not quickly suppressed. However, temperatures in Test 9 indicate that the fire was under control and being extinguished after the last sprinkler actuation at 9 min 1 s after ignition. Fire damage did not extend to the ends of the arrays and the maximum ceiling steel temperature was 56 $^{o}$C (133 $^{o}$F).

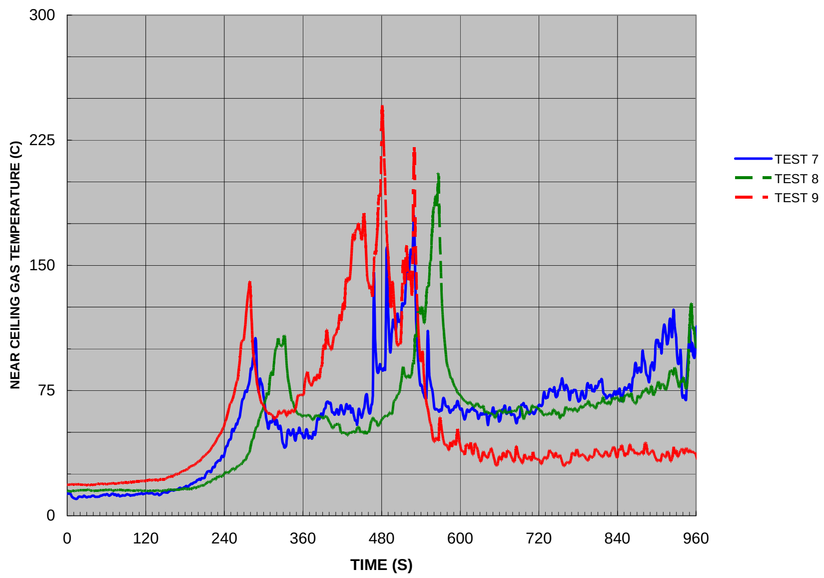


**FIGURE 6.** Near ceiling gas temperatures over array center – (Tests 7, 8 and 9)

Test 10 was the second of the two-test validation test for K360 sprinkler performance at the 12.2 m (40 ft) building height. Test 10 evaluated the low-storage-height (7.6 m [25 ft]), large-ceiling-clearance condition with the array centered below one sprinkler. The fire was suppressed with one operating sprinkler.

## DISCUSSION AND CONCLUSIONS

The large ceiling clearance fire tests used 4.6 m (15 ft)-high rack storage arrangements of exposed, unexpanded plastics, i.e., high density polyethylene plastic (HDPE) plastic pallets, under 13.7 m (45 ft), 15.2 m (50 ft), 16.7 m (55 ft) and 18.3 m (60 ft) ceilings. At ceiling heights of 13.7 m (45 ft) and 15.2 m (50 ft) these fire tests showed adequate sprinkler protection with a single sprinkler operation in each test. When ceiling heights were increased to 16.7 m (55 ft) and 18.3 m (60 ft) the fires could not be suppressed.

However, the sprinkler evaluation two-test protocol indicated that sprinkler protection was not adequate even at the 13.7 m (45 ft) ceiling height. Protection of this commodity in 12.2 m (40 ft)-high buildings was adequate only at a system pressure of 4.1 bar (60 psi). Since the 13.7 m (45 ft) ceiling height test was unsuccessful a 15.2 m (50 ft) ceiling height test was not attempted due to the high likelihood of failure.

The results of these tests indicate that a large ceiling clearance is not the more severe fire hazard condition for high buildings (up to 18.3 m [60 ft]). The more serious fire challenge is the result of the maximum allowed storage height which is accurately assessed by a two-test sprinkler evaluation protocol. The two-test test protocol proved more reliable for evaluating the fire suppression capability of K360 sprinklers at ceiling heights up to 18.3 m (60 ft).

## REFERENCES


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