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USE OF QUICK RESPONSE SPRINKLERS FOR INDUSTRIAL FIRE PROTECTION APPLICATIONS

by

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SUMMARY

Two sprinklered fire test programs were conducted to compare the performance of commercially available standard spray and quick response sprinklers in a wet pipe system for two different industrial fire protection challenges. One scenario simulated a storage occupancy, and the second scenario simulated a solid pile storage occupancy.

Based upon the results of these tests, it appears that quick response sprinklers can be used for the two occupancies investigated without significant concern regarding the possibility of undesired sprinkler actuations. The results indicate that if the sprinkler protection system has been properly designed for use with standard spray sprinklers, the substitution of quick response sprinklers will not compromise the existing level of protection.

INTRODUCTION

Recently, a number of sprinkler manufacturers began offering a modified version of a standard spray sprinkler in which the conventional response actuation mechanism had been replaced by a quick response actuation mechanism. These quick response sprinklers have been recommended for installation on a one-for-one basis in industrial occupancies replacing existing standard spray sprinklers. The water distribution patterns for these quick response sprinklers are the same as for standard spray sprinklers, and at this time, no changes in water discharge rates are recommended for cases in which the sprinklers are to be installed on a retrofit basis. This is entirely different from the approach taken in residential[1,2] and ESFR[3,4]* sprinkler development programs in which special attention was focused upon determining effective spray patterns and adequate water delivery rates necessary for achieving suppression. Since standard spray sprinklers are designed to provide fire control rather than suppression, the question of undesired sprinkler operations for these quick response standard sprinklers becomes important. The concern is that for multiple sprinkler arrangements typical of industrial applications, the more sensitive actuation mechanisms employed by quick response sprinklers could be actuated by the temperature buildup at the ceiling that exists for a finite period even after the fire is under control.

To address this concern, two sprinklered fire test programs[5,6] were conducted to compare the performances of standard spray and quick response sprinklers for two different industrial fire protection applications. The objectives of the tests were to determine (1) if there were any significant advantages for use of quick response sprinklers for industrial applications, and (2) whether quick response sprinklers were more prone to undesired sprinkler actuations than standard spray sprinklers in cases where fires are likely to be controlled rather than suppressed. A different protection scenario was used for each test series. One scenario simulated a relatively high-challenge rack storage occupancy. The second scenario simulated a reduced challenge solid pile storage arrangement.

*An acronym for the Early Suppression Fast Response sprinkler research program conducted by Factory Mutual Research Corporation. An outline of the program and the findings are presented in References 3 and 4.

The approach to the program was to compare the performances of quick response and standard spray sprinklers under identical initial test conditionsin a wet pipe system. This required use of quick response and standard spray sprinkler pairs which were identical in all respects, i.e., nozzle, frame and deflector, with the only exception being the actuation mechanism. Using this approach, the single independent variable in direct comparison tests was the sensitivity of the sprinkler actuation mechanism.

Of interest in evaluating sprinkler performance were the total numbers of sprinkler operations, fire sizes at first sprinkler operation, fire damage to fuel arrays, and ceiling damage potential in the protected occupancies.

Test Setups

The commodity used in these tests consisted of polystyrene plastic cups in 0.53 m x 0.53 m x 0.51 m compartmented cardboard cartons. Each carton contained 125 one-half liter capacity polystyrene cups in separate compartments. The carton weighed 6.4 kg, 3.6 kg of which was the plastic cups.

All tests were conducted in a full-scale test facility having a 9.1 m floor-to-ceiling clearance. Ninety-four sprinklers were installed on 3 m x 3 m spacing over the test area. Branch lines were 51 mm nominal diameter piping located 0.3 m below the ceiling. In both test series, the sprinklers used were 13 mm diameter orifice, upright types installed with links 0.2 m below the ceiling, as shown in Figure 1. For both test programs, the standard spray sprinklers were Factory Mutual Research Approved and Underwriters' Laboratories (UL) Listed, while the quick response sprinklers were listed by Underwriters' Laboratories only.

Instrumentation consisted of thermocouples for measuring near-ceiling gas temperatures at 17 selected locations over the test area, velocity (bidirectional differential pressure type) probes at ceiling over ignition and 1.2 m lengths of steel angle (50 mm x 50 mm, 6.6 mm thick) instrumented with thermocouples and installed at two ceiling locations (directly over ignition and 3 m to the west of ignition), which allowed an assessment of ceiling damage potential. The thermocouples used for gas temperature measurements were 28 gage chromel-alumel; thermocouples used for steel temperature measurements were 20 gage chromel-alumel thermocouples peened to the metal.

The near-ceiling gas temperature measurements were used to allow qualitative assessments of fire control and to validate sprinkler operations. Steel temperature measurements were compared with a damage criterion which specifies an unacceptable thermal exposure as a temperature in excess of 538°C (1000°F) for more than six minutes[7].

In both test series, a heat flux gage was installed at the face of one target array at one-half the array height. Ignition studies conducted by Khan[8] determined that a minimum heat flux of 10 kW/m^2 was required to ignite sheet cardboard of the type used in the construction of target array cartons used in these tests.

The central portion of the main fuel arrays containing ignition was placed upon a weighing platform to monitor the mass loss of the fuel. The 2.4 m by 2.4 m weighing platform was constructed using an I-beam frame covered with steel sheathing and gypsum board. It rested upon four load cells, one placed at each corner. The mass loss data were used to determine mass burning rates. Mass burning rates for the fuel packages were correlated with data from previous freeburn fire tests[9,10,11]. These data were used to determine convective heat release rates for the commodities until the application of sprinkler water, thereby providing information regarding relative fire sizes at first sprin-

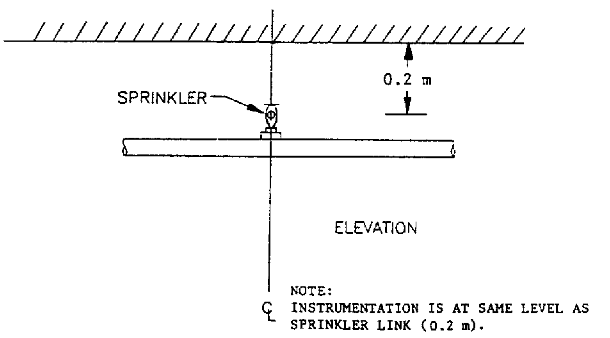


Figure 1. Sprinkler Position Relative to Ceiling.

TABLE 1

SUMMARY OF TEST CONDITIONS - STORAGE SCENARIO

Test Number	Sprinkler	Type	RTI $(m \cdot s)^{1/2}$*	Ignition Configuration
1	Manufacturer A	Standard Spray	142	Under One
2	Manufacturer A	Quick Response	30	Under One
3	Manufacturer B	Standard Spray	218	Under One
4	Manufacturer B	Quick Response	37	Under One
5	Manufacturer B	Standard Spray	218	Between Two
6	Manufacturer B	Quick Response	37	Between Two
7	Manufacturer A	Quick Response	30	Between Two

*Response Time Index (RTI) is a relative measure of the sensitivity of thermal response for a sprinkler actuation mechanism. Detailed explanation can be found in References 12 and 13. The RTI values for quick response sprinklers are typically in the range 22 to 55 $m^{1/2}s^{1/2}$. Standard spray sprinklers have RTI values of approximately 110 to 385 $m^{1/2}s^{1/2}$. These values represent the apparent RTI and do not include a conduction effect.

kler actuation for quick response and standard spray sprinklers. It was expected that because of the relatively large fuel array top-to-ceiling clearances for the two fuel arrays, the fires investigated would be well established at the time of first sprinkler actuation.

Rack Storage Scenario

Seven full-scale fire tests were conducted using the rack storage scenario. A summary of initial test conditions is presented in Table 1. The fuel array for these seven tests, shown in Figure 2, consisted of 3.1 m high rack storage arrangements of cartoned plastic. There was a 6 m clearance from the top of the fuel array to the ceiling. The main fuel array was ten pallets long by two pallets deep by two pallets high, as shown in Figure 3. The target arrays, each six pallets long by one pallet deep by two pallets high, were located across 2.4 m aisles on both sides of the main array.

Ignition was at the base of the bottom tier at the center of the main array. Two ignition-sprinkler configurations were used in this test series.

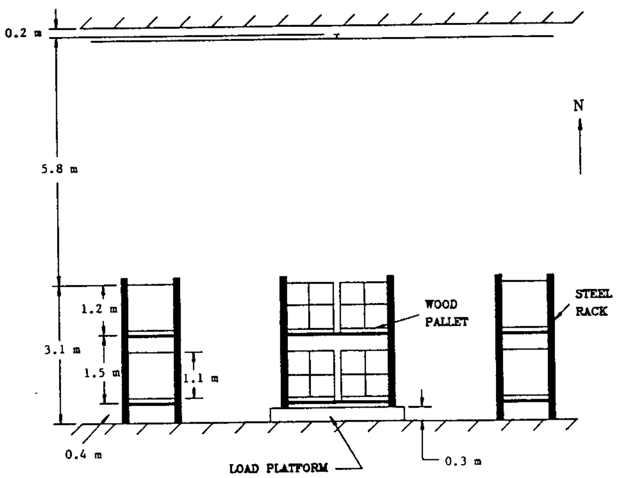


Figure 2. Rack Storage Scenario.

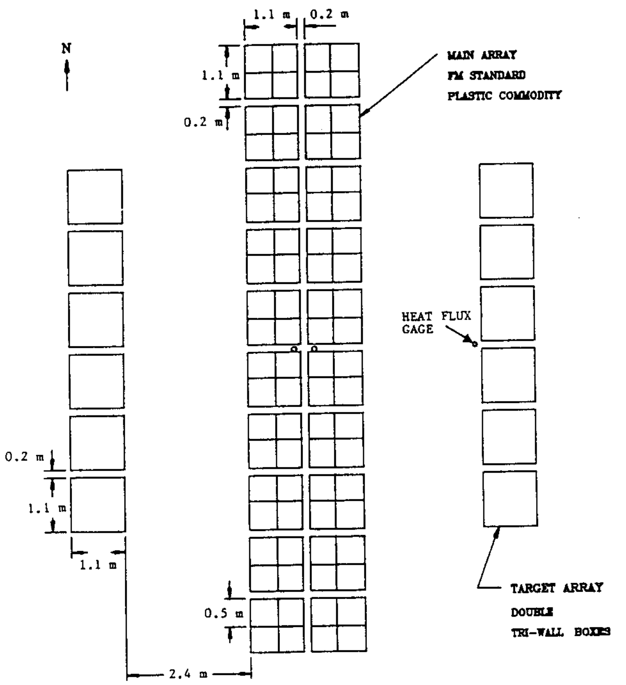


Figure 3. Rack Storage Scenario (Plan view).

For the initial four tests, ignition in the main fuel array was centered directly under a sprinkler. In the remaining three tests, the ignition point was centered below two sprinklers.

Two pairs of 74°C temperature-rated, upright type, 13 mm diameter orifice sprinklers were tested in this series. In these tests, sprinklers were discharged at a constant pressure of 462 kPa, which supplied each sprinkler with 170 ℓ/min.

For each sprinkler pair, identified as A and B in Table 1, the identical frame/deflector combination was used, but classified as either quick response or standard spray. The quick response sprinkler from Manufacturer A had a Response Time Index (RTI) of 30 $m^{1/2}s^{1/2}$, and the standard spray sprinkler had an RTI of 142 $m^{1/2}m^{1/2}$. The RTI values for Manufacturer B were 37 $m^{1/2}s^{1/2}$, and 218 $m^{1/2}s^{1/2}$ for quick response and standard spray sprinklers, respectively. These values represent the "apparent" RTI values as determined by the FMRC plunge test[12,13] and do not take into consideration conductive heat losses by the actuation link. Heskestad and Bill[14] found that when exposed to a fire environment, sprinkler actuation mechanisms conduct heat to the surrounding frame, fittings and piping prior to actuation. This heat loss, quantified in a parameter called the conduction factor "C", can, if large enough, significantly affect the time interval to sprinkler actuation. The rate and magnitude of the heat loss by the actuation mechanism depends upon several factors, including the mass and material composition of the sprinkler and its actuation mechanism, the absence or presence of stagnant water in the piping, type of pipe sealant, sprinkler mounting torque, and the depth of sprinkler nozzle thread engagement into the pipe fitting. Heskestad and Bill determined that for a given sprinkler and mounting condition, the heat loss effect was much more significant at the low gas temperatures and velocities characteristic of small or steady fires. Since fires

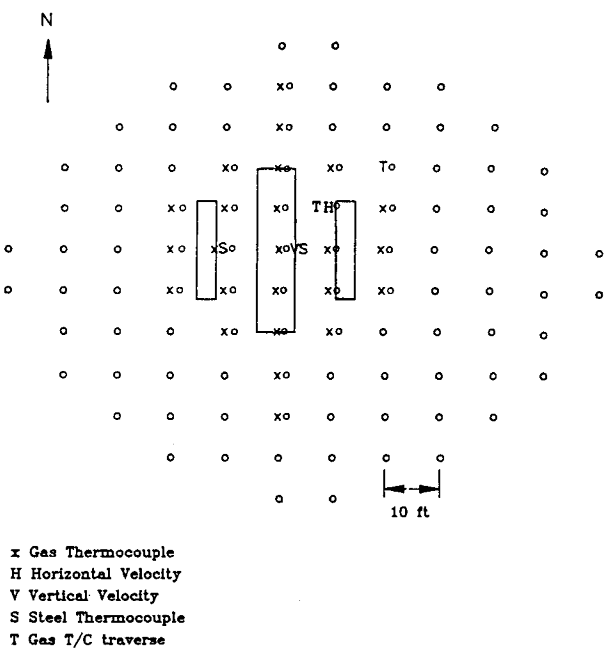
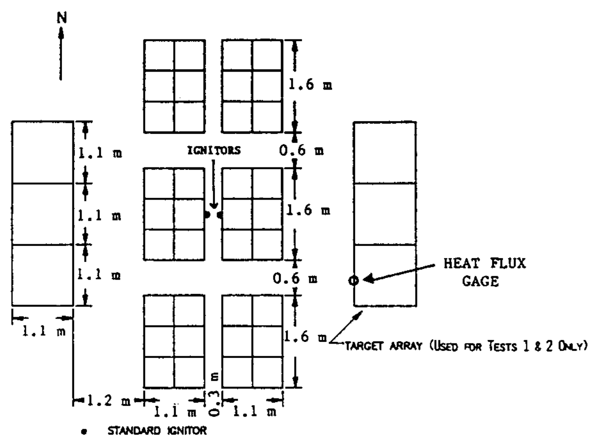


Figure 4. Rack Storage Scenario Instrument Layout. Ignition Under One Sprinkler.



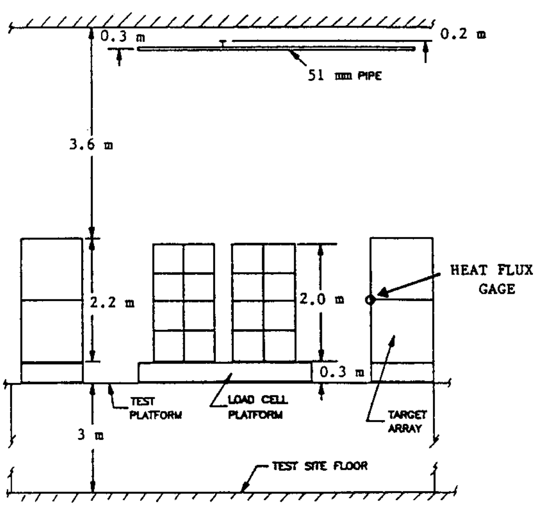


Figure 5a. Solid Pile Storage Scenario (Plan View).
Figure 5b. Solid Pile Storage Scenario (Front View).

TABLE 2

INITIAL TEST CONDITIONS - SOLID PILE STORAGE SCENARIO

Test No.	Sprinkler Manufacturer (Actuation)	RTI Rating* $(m{\bullet}s)^{1/2}$	Temperature Rating (°C)	Initial Temperatures Ceiling** (°C)	Initial Temperatures Ambient***	Relative Humidity***
1	F Standard Spray (L)	218	74	19	18	32
2	F Fast Response (L)	37	74	19	19	35
3	M Standard Spray (L)	142	74	21	19	19
4	M Fast Response (L)	30	74	21	19	14
5	K Standard Spray (L)	185	74	17	16	12
6	K Fast Response (L)	28	74	23	22	28
7	Q Standard Spray (L)	127	74	16	17	10
8	Q Fast Response (L)	26	71	19	16	14
9	S Standard Spray (B)	234	68	21	16	—
10	S Fast Response (B)	42	68	24	20	24
11	Y Fast Response (B)	44	68	27	23	18
12	W Fast Response (B)	40	68	21	20	29

(L) - Mechanical Link Actuation Mechanism
(B) - Bulb Actuation Mechanism

* Apparent RTI. Measured without consideration of conduction effects.
** T/C at Location 42 directly over ignition.
*** Measured at the 1.5 m level adjacent to the fuel array.

examined for this study were fast developing types, this effect would be small for the sprinklers tested. Therefore, the measurement of conduction factors was not undertaken for sprinklers evaluated in this program.

Figure 4 shows the instrumentation layout for the case in which ignition was centered under one sprinkler. For the case with ignition centered below two sprinklers, the fuel arrays were shifted 1.5 m to the south. Thermocouples for measuring gas temperatures and velocity probes were placed 0.2 m down from the ceiling. Two thermocouple traverses, with thermocouples at 0.05, 0.1, 0.2, 0.36 and 0.51 m from the ceiling, were placed at first and second ring sprinkler locations to the northeast of ignition.

Solid Pile Storage Scenario

A total of 12 fire tests was performed using a solid pile storage fuel package developed by the National Fire Protection Research Foundation (NFPRF), which was evaluated in a series of freeburn tests conducted at FMRC[10]. This same fuel package was subsequently investigated by Underwriters Laboratories in a fire suppression program in which Required Delivered Density (RDD) tests were performed[15].

A summary of initial test conditions for this scenario is presented in Table 2. The test setup consisted of six 2 m high solid pile stacks of the cartoned plastic commodity used in the first scenario flanked by two target arrays (see Figure 5). The target arrays consisted of stacked 1.1 m cube double triwall cardboard cartons located across 1.2 m aisles. A 3 m high platform was constructed to hold the test arrays and provided a 6.1 m floor-to-ceiling clearance for the fuel arrays. This left a 3.9 m clearance from the top of the fuel array to the ceiling.

Figure 6 shows the instrumentation layout for the solid pile storage scenario. As in the first test series, the instrumentation consisted of thermocouples at selected locations over the test

TABLE 3

SPRINKLER PERFORMANCE SUMMARY - RACK STORAGE SCENARIO

Test NO.	Sprinkler	Ignition Location	RTI (m•s)1/2	First Sprinkler Actuation Time (min:s)	First Sprinkler Actuation Fire Size* (kW)	Last Sprinkler Actuation Time (min:s)	Total Sprinkler Operations
1	A/Std.**	Under One	142	0:49	1,370	6:36	32
2	A/Q.R.	Under One	30	0:35	700	9:10	40
3	B/Std.**	Under One	218	0:55	1,490	7:03	29
4	B/Q.R.	Under One	37	0:43	500	6:00	27
5	BJ/Std.**	Between Two	218	0:55	—	8:49	26
6	B/Q.R.	Between Two	37	0:52	1,000	7:51	31
7	A/Q.R.	Between Two	30	0:39	1,050	8:12	32

* Fire size at first sprinkler actuation.
** Std. denotes a standard spray sprinkler

area, velocity probes, steel temperature measurements and a heat flux gage located on the face of one target array (shown in Figure 5).

Ignition in the main fuel array was centered directly under a sprinkler for all tests in this series.

Sprinklers used for this series were 13 mm diameter orifice, upright types with temperature ratings between 68°C to 74°C and RTI values ranging from 26 to 234 $m^{1/2}s^{1/2}$. Sprinklers from seven different manufacturers (coded as Manufacturers F, M, K, Q, S, Y, and W) were tested. Four manufacturers (Manufacturers F, M, K, and Q in Table 2) had quick response/standard spray sprinkler pairs which were identical in every respect, i.e., same nozzle, frame and defector, but one had a quick response actuation mechanism while the other had a standard link. Eight tests (Tests 1-6, 9, and 10) were performed to evaluate these four sprinklers. One manufacturer, Manufacturer Q, produced a quick response sprinkler and a standard spray sprinkler which were also evaluated in direct comparison tests (Tests 7 and 8). While the nozzles for the two sprinklers from Manufacturer Q were the same, there were obvious differences in frame and deflector designs which would result in differences in their water distribution patterns. The last two tests of the series (Tests 11 and 12) were performed using quick response frangible bulb sprinklers from two different manufacturers (Manufacturers Y and W).

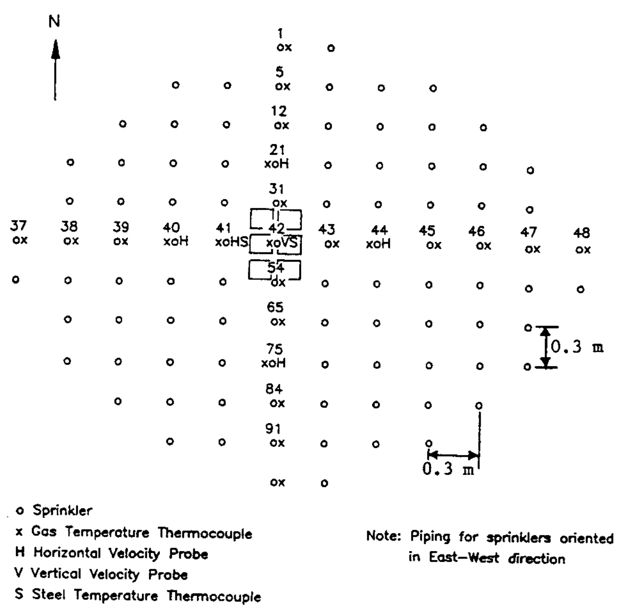


Figure 6. Solid Pile Storage Scenario Instrument Layout.

The water supply for the sprinkler system was designed to provide a declining discharge pressure using computer control of the feed pump discharge pressure. The system was initially charged to a pressure of 207 kPa. At this pressure each sprinkler discharges approximately 116 ℓ/min

TABLE 4

DAMAGE POTENTIAL DATA - RACK STORAGE SCENARIO

Test Number	Maximum Temperature Over Ignition* Gas	Steel (°C)	Steel Exposure** Over Ignition (min:sec)	Peak Heat Flux*** (kW/m²)	Fuel Array Damage Estimate (%)
1	226 (0:49)	84 (7:20)	0	31	42
2	137 (0:34)	86 (6:19)	0	26	36
3	277 (0:54)	84 (6:25)	0	38	35
4	173 (0:43)	84 (5:56)	0	22	24
5	1046 (5:17)	652 (8:41)	4:48	25	30
6	1053 (7:00)	615 (9:25)	3:24	20	29
7	1084 (5:10)	500 (6:17)	0	19	26

* Time of occurrence.
** Exposure duration with steel temperature over ignition in excess of 538°C (1000°F).
*** Heat flux measured at 1.5 m elevation across 2.4 ft aisle at east target array.

assuming a k-factor of 8.1 ℓ/min/(kPa)$^{1/2}$ for the nominal 13 mm diameter orfice sprinklers used in these tests. For each sprinkler actuation after the first, the system pressure was reduced in decrements of 8.3 kPa until 15 sprinkler operations had occurred. A minimum pressure of 82.7 kPa was then maintained, providing a discharge rate of 73 ℓ/min per sprinkler.

TEST RESULTS

The two scenarios tested presented different fire challenges to the sprinklers, which resulted in differences in the relative performances of quick response and standard spray sprinklers in the two fire test series. In both scenarios, fires were controlled by sprinklers and prevented from extending to the ends of the main arrays. The quick response sprinklers actuated at earlier stages of fire growth which reduced maximum near-ceiling gas temperatures. However, early actuation did not translate into significant reductions in maximum ceiling steel temperatures because the fires were not suppressed for these scenarios.

Rack Storage Scenario

A sprinkler performance summary for these tests is presented as Table 3.

Fire sizes at first sprinkler actuation (shown in Table 3) for the case with ignition centered under one sprinkler were estimated to be 700 kW and 500 kW for the two quick response

TABLE 5

SPRINKLER PERFORMANCE SUMMARY - SOLID PILE STORAGE SCENARIO

Test No.	Sprinkler	RTI $(m\bullet s)^{1/2}$	First Sprinkler Actuation Time (min:s)	First Sprinkler Actuation Fire Size* (kW)	Last Sprinkler Actuation Time (min:s)	Total Sprinkler Operations
1	F/Std.**	218	1:26	1,050	5:10	25
2	F/Q.R.	37	1:01	420	7:05	8
3	M/Std.**	142	1:17	690	2:55	10
4	M/Q.R.	30	0:49	480	11:47	6
5	K/Std.**	185	1:17	970	7:05	20
6	K/Q.R.	28	0:53	—	5:12	9
7	Q/Std.**	127	1:16	600	2:34	7
8	Q/Q.R.	26	1:32***	1,520 ***	1:59	10
9	S/Std.**	234	1:18	1,350	2:45	9
10	S/Q.R.	42	0:46	460	3:16	7
11	Y/Q.R.	44	1:01	390	6:20	7
12	W/Q.R.	40	0:49	470	4:26	11

* Fire size at first sprinkler actuation.
** Std. denotes a standard spray sprinkler.
*** Sprinkler other than one directly over ignition actuated first. The sprinkler directly over ignition operated at 1:58.

sprinklers (Tests 2 and 4, respectively), and 1,370 kW and 1,490 kW for the standard spray sprinklers (Tests 1 and 3, respectively), Maximum ceiling gas temperatures over ignition for Tests 1-4 (see Table 4) were less than 300°C, with the lower temperatures recorded for tests in which quick response sprinklers were used. Maximum steel temperatures were less than 100°C, and no significant differences were noted for the two types of sprinklers.

With ignition centered below two sprinklers (Tests 5-7), fire sizes at first sprinkler actuation were 1,000 kW and 1,050 kW for the two quick response sprinklers (Tests 6 and 7, respectively). Unfortunately, a malfunction of the load cell system prevented the determination of the fire size for the standard spray sprinkler used in Test 5. Maximum ceiling gas and steel temperatures measured directly over ignition, shown in Table 4, were considerably higher for these last three tests than for the first four tests. This is because the thermocouple measuring the ceiling gas temperature over ignition was 1.5 m away from the nearest sprinkler (with ignition between two). Consequently, the thermocouple did not receive the same level of cooling by sprinkler spray as it did when located right next to the sprinkler directly over ignition (Tests 1-4). Maximum ceiling gas temperatures were in the range 1053° to 1084°C with no significant differences between quick response and standard spray sprinkler tests. Maximum steel temperatures were 500° to 652°C. For the matched pair of sprinklers, i.e., Tests 5 and 6, use of the quick response sprinkler resulted in a slightly lower maximum steel temperature. However, the more significant difference was noted between the performances of sprinklers from the two different manufacturers.

Fire damage was generally confined to the two pallet long by two pallet deep central core of the main array. Although heat flux measurements at target arrays were greater than the 10 kW/m^2 minimum required for the ignition of cardboard[8], target arrays became involved only during Tests 1, 2, and 3, in which ignition was centered directly under a sprinkler. In these three tests, the peak heat fluxes recorded at the faces of the target arrays were 26 to 38 kW/m^2. However, this involvement was confined to

TABLE 6

DAMAGE POTENTIAL DATA - SOLID PILE STORAGE SCENARIO

Test No.	Max Temperature Over Ignition (°C) Gas	Steel	Peak Heat Flux (kW/m²)	Fuel Array Damage Estimate (%)
1	241 (1:26)	119 (5:32) (1)	7.6	30
2	——(2)	59 (4:47)	4.1	10
3	183 (1:17)	50 (2:28)	9.1	10
4	118 (0:46)	51 (7:05)	2.2	20
5	279 (1:17)	109 (7:00)	6.9	20
6	123 (0:53)	54 (6:58)	3.8	20
7	233 (1:16)	64 (3:23)	4.4	10
8	685 (1:50)	84 (6:15)	3.8	20
9	343 (1:18)	108 (4:22)	5.4	20
10	154 (0:46)	52 (6:04)	3.2	10
11	128 (0:58)	53 (6:42)	3.2	10
12	140 (0:49)	61 (6:22)	5.0	10

1 Time of occurrence.
2 Equipment malfunction.

carton surfaces facing the main ignition array and did not extend to the ends of target arrays. The quick response sprinklers used in Tests 2 and 4 provided significant reduction in fire damage when compared to their standard spray counterparts evaluated in Tests 1 and 3. Fire damages for tests in which ignition was centered below two sprinklers (Tests 5, 6, and 7) provided no clear indication of an advantage in using either fast response or standard spray sprinklers. No involvement of target arrays occurred in these tests in which ignition was centered below two sprinklers.

With ignition in the fuel array centered directly below a sprinkler, the standard spray sprinklers yielded 32 and 29 operations in Tests 1 and 3, respectively, while quick response sprinklers recorded 40 and 27 actuations during Tests 2 and 4. When ignition was centered below two sprinklers (Tests 5, 6, and 7), the standard spray sprinkler tested had only 26 actuations, and the two quick response sprinklers recorded totals of 31 and 32 actuations.

Solid Pile Storage Scenario

A summary of sprinkler performance for the solid pile storage scenario is presented in Table 5. For this reduced fire challenge scenario, the quick response sprinklers offered significant improvement over standard spray sprinklers. As a group, the quick response sprinklers operated at earlier stages of fire growth and produced fewer actuations than the standard spray sprinklers.

The only exception occurred in Test 8, involving the quick response sprinkler, when the sprinkler directly over ignition actuated 26 seconds after first sprinkler actuation (see Table 5). This was the only test in which first sprinkler actuation did not occur directly over ignition and made this test inconsistent with all others in this series. Review of test data and videotapes of this fire test provided no explanation for this anomaly. If Test 8, in which the temporary sprinkler skipping occurred, is excluded, fire sizes at first sprinkler actuation for quick response sprinklers were between 390 to 480 kW. For the standard spray sprinklers, fire sizes varied from 660 kW for the sprinkler used in Test 7 (RTI of 127 $m^{1/2}s^{1/2}$) to 1,350 kW for the sprinkler used in Test 9 (RTI 234 $m^{1/2}s^{1/2}$). Because quick response sprinklers actuated at earlier stages of fire growth than the standard spray sprinklers, maximum ceiling gas temperatures (shown in Table 6) were lower than those recorded for standard spray sprinklers. Maximum ceiling gas temperatures were below 350°C for all tests, with the exception of Test 8 in which temporary skipping of the sprinkler directly over ignition occurred. In Test 8, the maximum ceiling gas temperature reached 685°C. Maximum steel temperatures were below 165°C for all tests, with the lower maximum temperatures recorded for tests involving the quick response sprinklers.

Although the quick response sprinklers actuated faster as a group, all sprinklers tested controlled the fires and limited fire damages to the main array. There were no consistent differences in fire damage between quick response and standard spray sprinklers (Table 6). One explanation might be the tendency toward collapse of the fuel arrays during test. These stack collapses were random events which occurred in almost every test and appeared to diminish fire intensity and retard the progression of burning.

The number of actuations for quick response sprinklers ranged from seven to 11 actuations. In the direct comparison tests involving the four different sprinkler pairs (Tests 1-6, 9 and 10) in which quick response and standard spray sprinkler pairs possessed identical nozzle, frame and deflector combinations, the quick response version of each sprinkler produced fewer actuations in each case. For the remaining direct comparison tests (Tests 7 and 8) in which comparable, but not identical, sprinklers were evaluated, the standard spray sprinkler produced fewer actuations. Although non-fire water distribution measurements made for the two sprinklers used in Tests 7 and 8[6] indicated that the standard spray sprinkler would potentially provide more water to the top of the fuel array than the quick response version, the delayed actuation of the quick response sprinkler probably resulted in the higher number of sprinkler operations in Test 8.

CONCLUSIONS

As the result of two fire test series conducted in this program, the following conclusions are offered:

1. Quick response sprinklers actuated at earlier stages of fire growth in both test series, and as a result, limited near-ceiling gas temperatures below maxima recorded when standard spray sprinklers were used.

2. In these tests, it was the lower fire challenge (i.e., solid pile storage) scenario where the differentiation between the performance of quick response and standard spray sprinklers was greatest. In the solid pile storage scenario, on average, a significant improvement in the level of fire protection was achieved through use of the quick response sprinklers as indicated by maximum near-ceiling gas temperatures, peak heat flux to

target arrays, and the total numbers of sprinkler actuations. For the higher challenge fire challenge provided by the rack storage scenario, there appeared to be no significant advantage or disadvantage in the use of the quick response sprinklers.

3. It appears that quick response sprinklers can be successfully used for protection of the two occupancy scenarios investigated in this program without significant concern for undesired sprinkler actuations. If the sprinkler protection system has been properly designed for use with standard spray sprinklers, then the substitution of quick response sprinklers will, at worst, not compromise the existing level of protection.

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