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PROTECTION OF WAREHOUSE RETAIL OCCUPANCIES WITH EXTRA LARGE ORIFICE (ELO) SPRINKLERS

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SUMMARY

A full-scale test program[1] was conducted at the Factory Mutual Research Corporation test facility to determine if existing or new technology fire sprinkler systems are capable of providing acceptable protection for high-piled storage found in warehouses and warehouse-type retail stores. Nine large-scale fire tests were conducted with double-row rack storage arrangements containing a cartoned Group A Unexpanded Plastic commodity. Protection was provided by Extra Large Orifice, 0.64 in. (16 mm), sprinklers installed at the ceiling only. Test variables included: building heights of 22 to 27 ft (6.7 to 8.2 m); storage heights of 14 to 20 ft (4.2 to 6.1 m), in conjunction with ignition location; sprinkler temperature rating; sprinkler discharge density; type of shelving (slatted wood, solid wood or wire mesh); flue spacing; and the presence of draft curtains. Test results show that a 0.60 gpm/ft^2 (24 mm/min) discharge density supplied over a 2000 ft^2 (186 m^2) design area will protect such storage; and reduced densities may be used under certain specific conditions.

BACKGROUND

A retailing concept, sometimes called a warehouse store or a superstore, in which retail stores and warehouses merge, has proliferated during the past 20 years. These warehouse stores display and sell retail merchandise in large quantities that is stacked in racks up to 20 ft (6.1 m) high; buildings typically cover more than 100,000 ft^2 (9290 m^2) and have ceilings up to 27 ft (8.2 m) high. This occupancy presents unique fire protection challenges due to: extensive public access, high rack storage, and large amounts of mixed commodities under one roof that may vary by season. Current protection standards for rack storage where high fire hazard commodities (*i.e.*, Plastics) are expected to be present require a high water demand, *i.e.*, extensive sprinkler application areas, high sprinkler discharge densities, and/or in-rack sprinklers. Installation of in-rack sprinklers is considered impractical in these facilities because: (1) the lower storage tiers are used for display or customer self-service; (2) display flexibility of seasonal products may be hindered; (3) rack resetting occurs frequently; and (4) products are continually restocked. These activities could cause accidental sprinkler openings.

In late 1992, the Group A Plastics Committee, representing retailers and product manufacturers, was formed to address fire protection and associated life safety issues presented by warehouse stores. The focus of the committee's study was the safe display and storage of Group A Plastic commodities. This fire hazard category includes products partly or wholly manufactured from materials such as polystyrene, polyethylene, and flexible polyvinyl chloride. (Protection of "special" or "extra" hazard commodities, such as flammable liquids, aerosols, rubber tires, and exposed expanded plastics, would not be addressed in the program; these items could be segregated and protected according to current guidelines using in-rack sprinklers.) Other concerns that could adversely affect the provided sprinkler protection in these

facilities included: the presence of wood shelving in the racks, the requirement that draft curtains subdivide ceilings, and the spacing and sizes of vertical flue spaces separating storage blocks.

A test program was planned that incorporated the technical expertise of representatives from the fire service and insurance industry, who were invited to join the Committee, and recent advances in sprinkler technology[2,3]. The referenced work demonstrated that Extra Large Orifice (ELO) sprinklers are capable of providing efficient, cost-effective protection using low system water pressure requirements for similar storage arrangements. An important goal of the program was to provide adequate protection without the use of in-rack sprinklers, while simultaneously minimizing the need for fire pumps or water storage reservoirs.

Test Program and Procedure

General Test Conditions

The test program consisted of nine large-scale fire tests (Table 1) conducted at the Factory Mutual Research Corporation (FMRC) Test Center in West Glocester, Rhode Island. All tests were conducted with double-row rack storage arrays containing a Cartoned Group A Unexpanded Plastic commodity. The arrays were erected on elevating platforms in the 30 ft (9.1 m) high test site to provide the selected ceiling heights. The test site is located under a continuous ceiling in the 50,000 ft^2 (4645 m^2) building. Each array consisted of a main double-row rack, where ignition would occur, that was paralleled by two single-row target racks. The arrays were designed to replicate rack storage situations found in warehouse-type retail occupancies in conjunction with arrangements used in previous FMRC large-scale fire testing (see Figure 1).

Test Commodity

The FMRC Standard Plastic test commodity served as the Group A Plastic fuel. The product is fabricated with 125 empty 16 oz (0.5 ℓ) polystyrene jars packaged in 21 in (0.5 m) cube compartmented corrugated paper cartons. Eight cartons are typically stacked on a wood pallet to form a "pallet load." In some tests in this program, individual cartons were placed in the lower, shallow storage tiers that were created in the arrays (see Figure 1b). The product has been used extensively in fire testing for more than 20 years and provides a high challenge fire[4].

Wood and Wire Mesh Shelving

A combination of wood and wire mesh shelving was installed on the rack rails in seven of the nine tests, duplicating conditions at some warehouse stores. The purpose was to assess the effects of the presence of shelving on fire behavior and sprinkler performance. Slatted wood shelving, consisting of 2 in x 6 in (5 cm x 15 cm) boards with 2 in (5 cm) separations was used in six tests. One test was run with solid wood shelving consisting of the same boards, but with no separations. The wood shelving was installed at the storage levels indicated in Figure 1b. An open-grid wire mesh shelving was installed only at the top tier in the same arrays.

Draft Curtains

Draft curtains were installed in two tests to assess their effects on fire development and sprinkler performance. Two intersecting 65 ft (19.8 m) long by 6 ft (1.8 m) deep draft curtains were installed over the storage arrays; curtain locations were coordinated with ignition locations to provide worst-case conditions.

Automatic Sprinkler Protection

Protection was provided by Extra Large Orifice (ELO), 0.64 in (16 mm) orifice diameter sprinklers. The upright model ELO-231 sprinklers were installed in 2 in (5 cm) diameter piping just below the test site ceiling. The distances between the ceiling and the sprinkler's deflector and fusible element were approximately 7 in (18 cm) and 8 in (20 cm), respectively. The sprinkler's K-factor is a nominal 11.4 gal/min/$psi^{1/2}$ (16.4 dm^3/min/$kPa^{1/2}$), and Response Time Index (RTI) is a nominal 300 $ft^{1/2}s^{1/2}$

Table 1. Fire Test Summary

Project: Group A Plastics Committee, Large-Scale Fire Tests in Retail Operation Scenarios
Test Commodity/Fuel: Cartoned Group A Unexpanded Plastic, FMRC Standard Plastic Test Commodity (Polystyrene Jars in Compartmented Cartons)
Storage Arrangement: Double-Row Rack Test Duration: 30 minutes

Sprinklers: Extra Large Orifice, Model ELO-231
Orifice Size = 0.64 in (16 mm)
K-Factor = 11.4 gal/min/psi$^{1/2}$ (16.4 dm^3/min/kPa$^{1/2}$)
RTI = 300 ft$^{1/2}$ s$^{1/2}$ (166 m$^{1/2}$s$^{1/2}$)

	Test No.	1	2	3	4	5	6	7	8	9
	Date of Test	8/20/93	8/25/93	9/2/93	9/29/93	10/7/93	2/17/94	2/25/94	4/27/94	8/3/94
CONDITIONS	Type of Shelving	Slatted Wood	Slatted Wood	Slatted Wood	Solid Wood	Slatted Wood	Slatted Wood	Slatted Wood	Wire Mesh	None
	Other Conditions / Inclusions	-	-	-	-	-	Draft Curtains	Draft Curtains	-	-
	Storage Height (ft. - in.) ((m))	19-11 (6.1)	19-11 (6.1)	15-4 (4.7)	19-11 (6.1)	15-4 (4.7)	19-11 (6.1)	15-4 (4.7)	13-11 (4.2)	18-11 (5.8)
	No. of Storage Tiers	6*	6*	5*	6*	5*	6*	5*	3	4
	Clearance to Ceiling (ft. - in.) ((m))	6-10 (2.1)	6-10 (2.1)	11-5 (3.5)	6-10 (2.1)	11-5 (3.5)	6-10 (2.1)	11-5 (3.5)	8-4 (2.5)	6-1 (1.9)
	Longitudinal / Transverse Flues (in.)	6 / 6 to 7-1/2	6 / 6 to 7-1/2	6 / 6 to 7-1/2	6 / 6 to 7-1/2	6 / 6 to 7-1/2	6 / 6 to 7-1/2	6 / 6 to 7-1/2	6 / 3**	6 / 6 to 7-1/2
	Longitudinal / Transverse Flues (cm)	15 / 15 to 19	15 / 15 to 19	15 / 15 to 19	15 / 15 to 19	15 / 15 to 19	15 / 15 to 19	15 / 15 to 19	15 / 8**	15 / 15 to 19
	Aisle Width (ft.) ((m))	7-1/2 (2.3)	7-1/2 (2.3)	7-1/2 (2.3)	7-1/2 (2.3)	7-1/2 (2.3)	7-1/2 (2.3)	7-1/2 (2.3)	7-1/2 (2.3)	9-1/2 (2.9)
	Ignition Centered below (No. of Spinklers)	2	2	1	2	1	2	1	1	2
	Sprinkler Temperature Rating (°F) ((°C))	165 (74)	286 (141)	286 (141)	165 (74)	165 (74)	165 (74)	286 (141)	286 (141)	286 (141)
	Sprinkler Spacing (ft. x ft.)	8 x 10	8 x 10	8 x 10	8 x 10	8 x 10	8 x 10	8 x 10	10 x 10	10 x 10
	Sprinkler Spacing (m x m)	2.4 x 3.1	2.4 x 3.1	2.4 x 3.1	2.4 x 3.1	2.4 x 3.1	2.4 x 3.1	2.4 x 3.1	3.1 x 3.1	3.1 x 3.1
	Constant Water Pressure (psi) ((kPa))	19 (131)	19 (131)	19 (131)	19 (131)	19 (131)	19 (131)	19 (131)	15.5 (107)	19 (131)
	Discharge Density (gpm/ft^2) ((mm/min))	0.60 (24)	0.60 (24)	0.60 (24)	0.60 (24)	0.60 (24)	0.60 (24)	0.60 (24)	0.45 (18)	0.50 (20)
RESULTS	First Sprinkler Operation (min:s)	2:03	2:25	1:12	1:43	0:44	1:25	0:52	0:55	o:49
	Last Sprinkler Operation (min:s)	2:12	15:19	6:34	13:49	7:34	15:54	14:08	5:29	10:58
	Total Sprinklers Opened	4	9	7	15	13	35	18	5	12
	Peak / Max. One Min. Avg. Gas Temp. (°F)	1107 / 566	1412 / 868	965 / 308	1466 / 717	662 / 184	1575 / 883	1162 / 767	996 / 383	1464 / 895
	Peak / Max. One Min. Avg. Gas Temp. (°C)	597 / 297	767 / 464	518 / 153	797 / 381	350 / 84	857 / 473	628 / 408	536 / 195	796 / 479
	Peak / Max. One Min. Avg. Steel Temp. (°F)	185 / 172	197 / 196	233 / 232	149 / 148	146 / 145	226 / 225	255 / 254	301 / 301	502 / 500
	Peak / Max. One Min. Avg. Steel Temp. (°C)	85 / 78	92 / 91	112 / 111	65 / 64	63 / 63	108 / 107	124 / 123	149 / 149	261/ 260
	No. of Pallet Loads Consumed	3	9	6	15	5	12	13	3	12
	Extent of Fire Spread Acceptable	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes
	Results Acceptable (Test Criteria Met)	Yes	Yes	Yes	No***	Yes	No****	No*/*	Yes	Yes

Notes: *Main (Ignition) Racks divided into five or six tiers; three bottom tiers each about 2 ft. (0.6 m) high and upper tiers each about 5 ft. (1.5 m) high. Wood shelving below commodity at second through fifth tiers; wire mesh shelving below commodity at sixth tier or above fifth (top) tier commodity in Tests 3 and 7. **Transverse flues spaced 8 ft (2.4 m) apart (versus 3 1/2 ft (1.07 m) apart in all other tests). ***Excessive fire spread. ****High water demand. */*Excessive fire spread. If the test array had been longer, additional sprinklers would have been expected to open. (FMRC J.I. 0X1R0.RR)

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(166 $m^{1/2}s^{1/2}$). Both 165 °F (74 °C) and 286 °F (141 °C) rated sprinklers were used in otherwise duplicate tests. The constant discharge densities supplied for specific tests ranged from 0.45 to 0.60 gpm/ft^2 (18 to 24 mm/min), as discussed below.

Instrumentation and Ignition Method

The following instrumentation was installed:

- sprinklers with timing mechanisms at 96 locations;
- thermocouples for gas temperature measurement near the ceiling at over 35 locations;
- thermocouples embedded in a steel angle located at the ceiling over the ignition point;
- fire plume velocity probes centered over the array and extending 4 ft (1.2 m) below the ceiling;
- and heat flux gages located on the targets opposite the ignition flues.

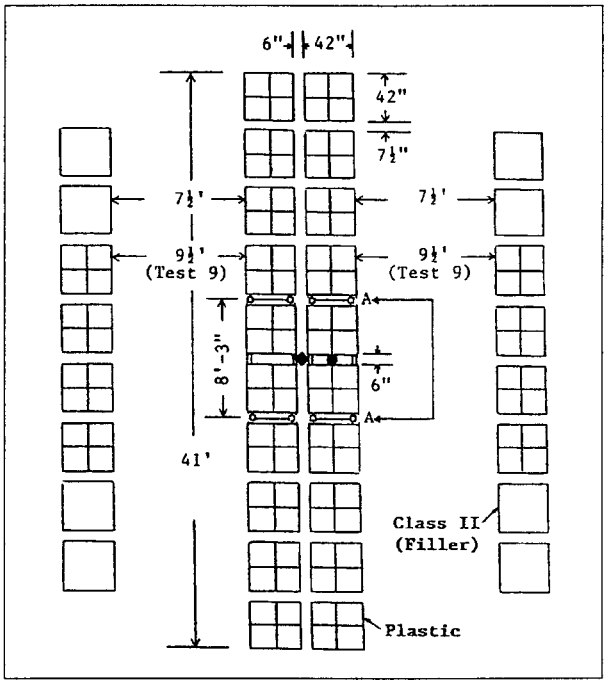


Figure 1a. Plan View (Typical of All Tests).

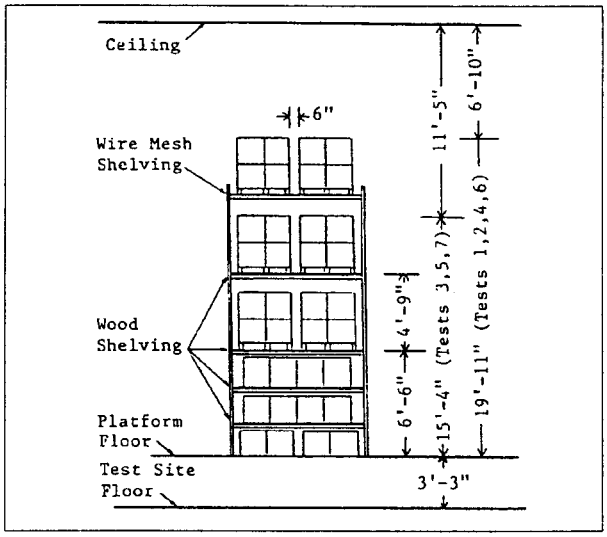


Figure 1b. A - A Elevation Tests 1 to 7.

Key:
● = Ignition Location Tests 1, 2, 4, 6 & 9.
◆ = Ignition Location Tests 3, 5, 7 & 8.

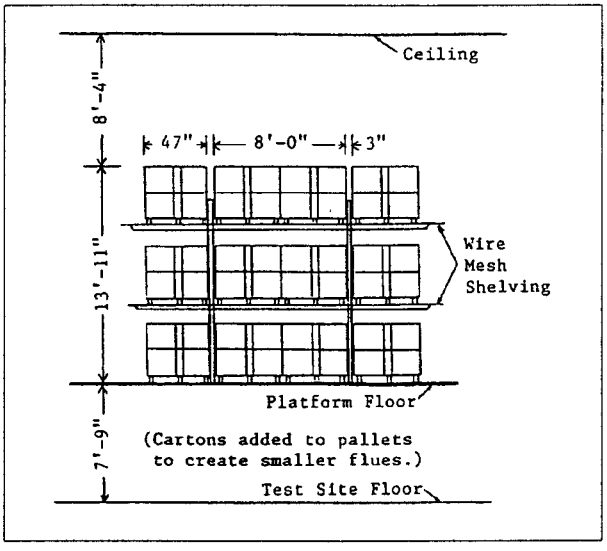


Figure 1c. A - A Elevation Test 8.

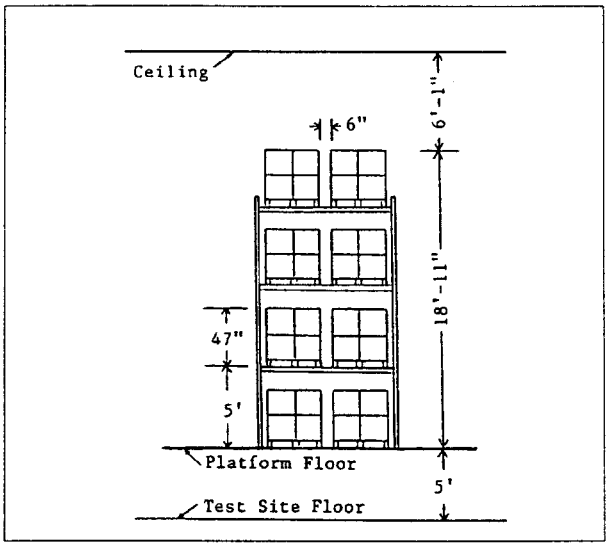


Figure 1d. A - A Elevation Test 9.

Figure 1. Rack Storage Test Arrangements.

Ignition was achieved with standard FMRC igniters, 3 in x 3 in (8 cm x 8 cm) cylinders of rolled cellucotton, each soaked in 4 oz (118 m ℓ) of gasoline. The rolls were placed at floor level, in the flues indicated in Figure 1a. After lighting the igniters, the fires were allowed to develop naturally. Two different ignition locations were used to explore the two worst-case fire scenarios identified in previous FMRC test programs[5,6]. Previous tests have shown worst-case ignition location can be correlated with ceiling sprinkler location, storage height, and ceiling clearance. The two scenarios are: (1) a fire starting between two sprinklers with low ceiling clearance (see Table 1 - Tests 1, 2, 4, 6, and 9); and (2) a fire starting directly below a sprinkler with high ceiling clearance (see Table 1 - Tests 3, 5, 7, and 8).

Criteria for Evaluating Test Results

Principal criteria used to evaluate results of the tests were:

1. Magnitude of the water demand. A maximum 2000 ft^2 (186 m^2) design area was desired.

2. Magnitude and duration of high ceiling level steel and gas temperatures. Temperatures sustained at levels that would result in damage to exposed structural steel would be unacceptable (e.g., steel temperatures in excess of 1180 °F (638 °C), and gas temperatures sustained at or above 1000 °F (538 °C) for more than 7 minutes have been judged unsafe).

3. Extent of fire damage. Confinement of the fire within the limits of the array was required.

Test Details and Results

Conditions: Test 1 through Test 7

For the first seven tests, the rack storage arrays simulated those found in a home improvement product warehouse store, wherein the lower 6 to 7 ft (1.8 to 2.1 m) of the rack is usually divided into several shallow tiers for customer self-service of individual products, and the upper tiers contain full pallet loads of products; a combination of wood and wire mesh shelving is installed in the racks. Both 20 ft (6.1 m) high and 15 ft (4.7 m) high arrays were set up under a 27 ft (8.2 m) high ceiling. The storage height (under the same ceiling height) and the location of the ignition point in the array with respect to the ceiling sprinklers were varied in the tests to provide worst-case conditions[5,6]. (See Figures 1a and 1b.) Other test variables included: two sprinkler temperature ratings; the substitution of solid wood shelving for slatted wood shelving; and the installation of draft curtains. ELO sprinklers operating at a constant 19 psi (131 kPa) discharge pressure supplied a 0.60 gpm/ft^2 (24 mm/min) discharge density for these tests.

Tests 1 and 2 and Tests 3 and 5 were identical pairs, except for the sprinkler temperature rating, and can be compared. Test 1 (with slatted wood shelving) and Test 4 (with solid wood shelving) were otherwise identical and can be compared. Tests 1 and 6 and Tests 3 and 7 can be compared; these pairs were identical except for the installation of draft curtains in Tests 6 and 7.

Results: Tests 1–3 and Test 5

Test 1 and Test 2 were conducted with 20 ft (6.1 m) high storage arrays; the ignition location was centered between two sprinklers. The tests were identical except for the sprinkler temperature rating. For Test 1, 165 °F (74 °C) rated sprinklers were installed; four sprinklers operated in the test. For Test 2, 286 °F (141 °C) rated sprinklers were used, and nine sprinklers operated. The fire was well confined to the racks of fire origin in Test 1, and the volume equivalent of three pallet loads of the test commodity was consumed. In Test 2, there was more damage, but not an excessive amount; nine pallet loads were consumed. Although fire reached an end of one of the ignition racks and one target rack was ignited, these fires were quickly controlled by successive

sprinkler openings. Temperatures in both tests remained well within safe levels. See Figures 2 and 3 and Table 1. (Note: On the figures, all sprinkler positions are not shown; numbers denote operating sequence. On the table, peak temperatures were momentary values; excessively high temperatures were not recorded in any test in the program.)

Test 3 and Test 5 were conducted with 15 ft (4.7 m) high storage arrays; the ignition point was located directly below a sprinkler. Again, identical tests were run with 286 °F (141 °C) and 165 °F (74 °C) rated sprinklers installed in Test 3 and Test 5, respectively, to explore the effects of temperature rating with this alternative ignition scenario, which combined lower storage with higher clearance. Results were opposite those of the first two tests. In Test 3, seven 286 °F (141 °C) rated sprinklers opened, and in Test 5, 13 165 °F (74 °C) rated sprinklers opened. Although the extent of fire damage patterns differed, fuel consumption was similar. The equivalent of six pallet loads was consumed in Test 3, and five were consumed in Test 5. Although both targets were ignited in Test 3, new seats of fire did not become established, and damage was minimal. Temperatures in both tests remained well within safe levels. (See Figures 4 and 5 and Table 1.) The test criteria were met by the four tests presented above. These good results established that the provided "ceiling only" protection using ELO sprinklers was effective for the warehouse retail occupancy.

Results: Test 4

Test 4 was conducted with 20 ft (6.1 m) high storage with ignition centered between two 165 °F (74 °C) sprinklers. The test was a duplicate of Test 1, except that solid wood shelving was installed instead of slatted wood shelving. Results were dramatically different from Test 1: 15 sprinklers opened; fire spread throughout the racks of fire origin; rack damage was extensive; and 15 pallet loads were consumed. Temperatures remained within safe levels and were not significantly higher than those recorded in Test 1. Results were typical of those of previous tests with solid shelving, where the fire is concentrated in the lower storage tiers shielded from the sprinkler discharge[7,8]. (See Figures 2 and 6 and Table 1.)

Results: Tests 6 and 7

Test 6 and Test 7 were repeats of Test 1 and Test 3, respectively, except for the installation of draft curtains. Results differed dramatically from those of the tests

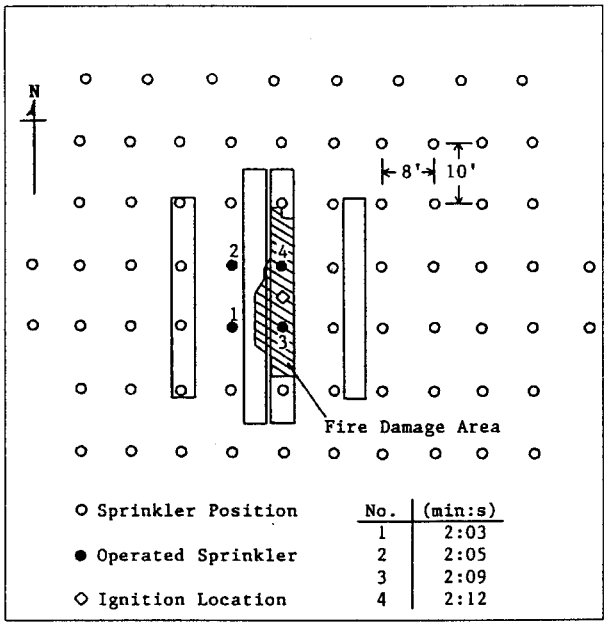


Figure 2. Sprinkler Operations and Overall Extent of Fire Damage - Test 1.

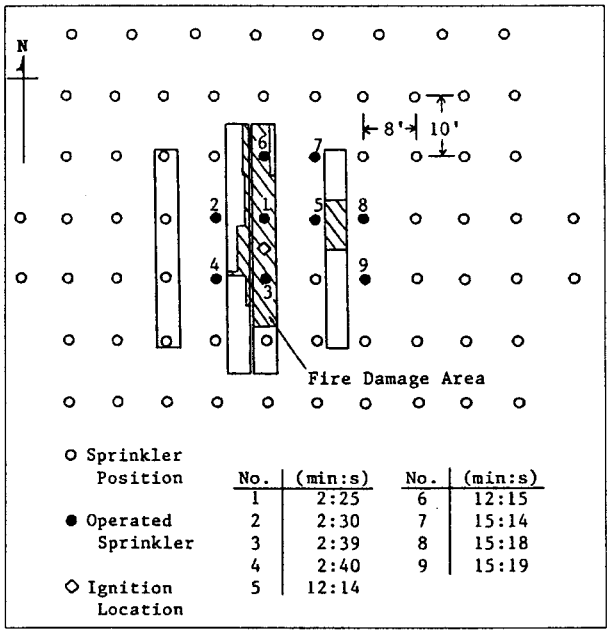
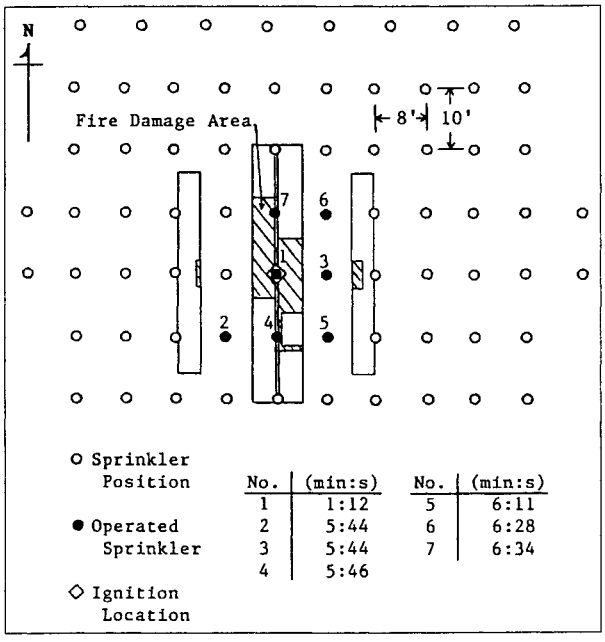


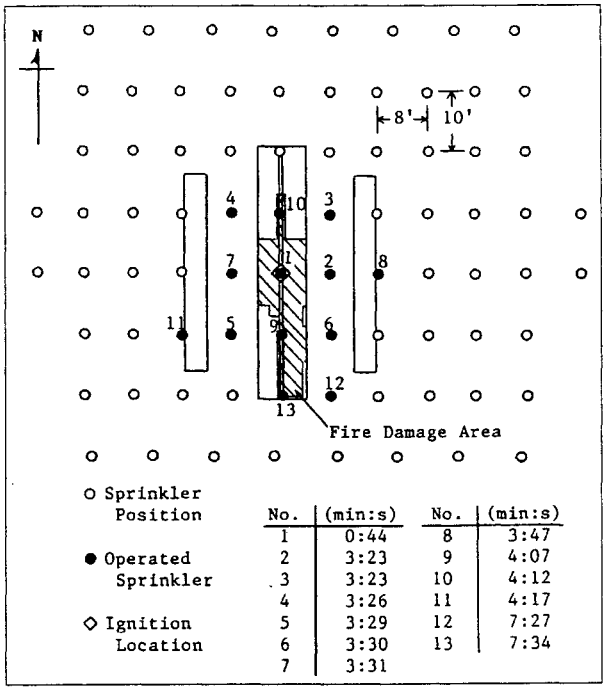
Figure 3. Sprinkler Operations and Overall Extent of Fire Damage - Test 2.

without draft curtains.
Test 6 was conducted with 20 ft (6.1 m) high storage with ignition centered between two 165 °F (74 °C) sprinklers. In Test 6, 35 sprinklers opened versus four in Test 1; fire spread was more extensive, and 12 pallet loads were consumed versus



No.	(min:s)	No.	(min:s)
1	1:12	5	6:11
2	5:44	6	6:28
3	5:44	7	6:34
4	5:46		

Figure 4. Sprinkler Operations and Overall Extent of Fire Damage - Test 3.



No.	(min:s)	No.	(min:s)
1	0:44	8	3:47
2	3:23	9	4:07
3	3:23	10	4:12
4	3:26	11	4:17
5	3:29	12	7:27
6	3:30	13	7:34
7	3:31		

Figure 5. Sprinkler Operations and Overall Extent of Fire Damage - Test 5.

three in Test 1. (See Figures 2 and 7 and Table 1.) In Test 6 (as in all tests in the program), peak temperature levels were not excessively high, but temperature histories showed the fire moving and redeveloping in the four quadrants bounded by the draft curtains. Graphs of peak temperatures from Test 1 and Test 6 (Figures 8 and 9) illustrate the differences in fire progress.

Test 7 was conducted with 15 ft (4.7 m) high storage with ignition directly below a 286 °F (141 °C) sprinkler. In Test 7, 18 sprinklers opened versus seven in Test 3; fire spread was more extensive, reaching the limits of the ignition racks and involving both targets. Thirteen pallet loads were consumed in Test 7 versus six in Test 3. Temperature patterns were similar to those experienced in Test 6. (See Figures 4 and 10 and Table 1.)

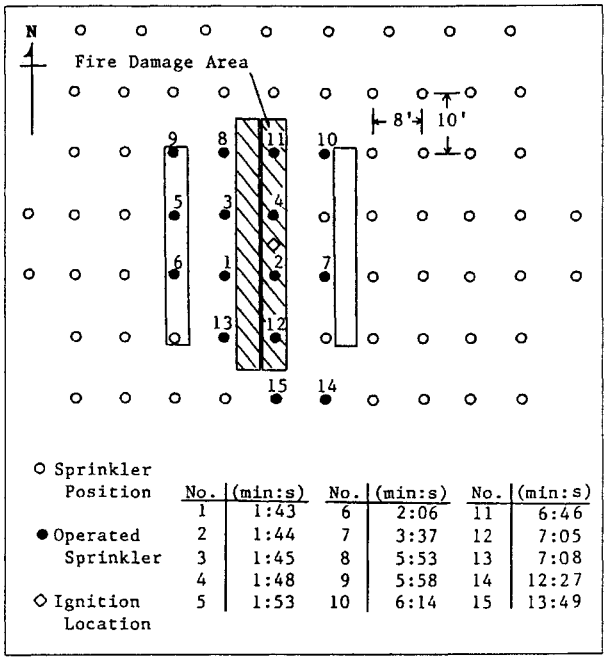
In Test 6 and Test 7, the draft curtains upset the normal symmetrical jet stream of the fire gases, which caused more sprinklers to open in an atypical pattern and some well away from the fire. These remote sprinklers had no effect on control. Smoke was driven down sooner in a wider area. Sprinkler discharge patterns were distorted, affecting prewetting of adjacent commodity, resulting in additional fire spread and sprinkler openings.

Conditions and Results: Tests 8 and 9

Test 8 and Test 9 were individual tests. The designated storage arrangements and protection criteria replicated conditions that exist in other (usually older) warehouse stores and/or storage areas of retail occupancies. Most important were the reduced discharge densities that were used.

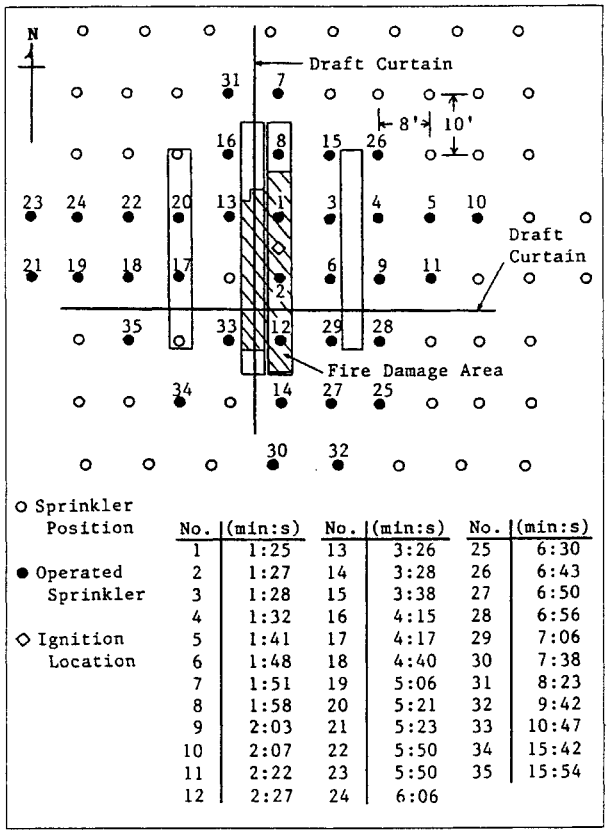
Test 8 was conducted with a 14 ft (4.2 m) high array divided into three uniform tiers, erected under a 22 ft (6.7 m) ceiling (Figure 1c). The effects of installing only wire mesh shelving in the racks and of reducing the size and number of transverse flues between storage blocks were investigated. Specifically, commodity was added to the two pallets in each rack bay, thereby maintaining 3 in (8 cm) transverse flues

only at the rack uprights. Ignition was located directly below a 286 °F (141 °C) ELO sprinkler. A 0.45 gpm/ft^2 (18 mm/min) discharge density was supplied. Five sprinklers controlled the fire. Damage was well confined to the racks of fire origin; three pallet loads were consumed. Temperatures remained well within safe levels. (See Figure 11 and Table 1.)



No.	(min:s)	No.	(min:s)	No.	(min:s)
1	1:43	6	2:06	11	6:46
2	1:44	7	3:37	12	7:05
3	1:45	8	5:53	13	7:08
4	1:48	9	5:58	14	12:27
5	1:53	10	6:14	15	13:49

Figure 6. Sprinkler Operations and Overall Extent of Fire Damage - Test 4.



No.	(min:s)	No.	(min:s)	No.	(min:s)
1	1:25	13	3:26	25	6:30
2	1:27	14	3:28	26	6:43
3	1:28	15	3:38	27	6:50
4	1:32	16	4:15	28	6:56
5	1:41	17	4:17	29	7:06
6	1:48	18	4:40	30	7:38
7	1:51	19	5:06	31	8:23
8	1:58	20	5:21	32	9:42
9	2:03	21	5:23	33	10:47
10	2:07	22	5:50	34	15:42
11	2:22	23	5:50	35	15:54
12	2:27	24	6:06		

Figure 7. Sprinkler Operations and Overall Extent of Fire Damage - Test 6.

Test 9 was conducted with a 19 ft (5.8 m) high array using an open-frame rack structure divided into four uniform tiers, erected under a 25 ft (7.6 m) ceiling (Figure 1d). No shelving was installed, and conventional flue spacing was employed. Aisles were 9.5 ft (2.9 m) wide versus 7.5 ft (2.3 m) in all previous tests. Ignition was located between two 286 °F (141 °C) ELO sprinklers. The discharge density was 0.50 gpm/ft^2 (20 mm/min). Twelve sprinklers controlled the fire. Damage was well confined to the racks of fire origin; 12 pallet loads were consumed. Temperatures remained well within safe levels. (See Figure 12 and Table 1.)

Discussion of Test Results

Acceptable Tests

For Tests 1, 2, 3, 5, 8 and 9, which were conducted with either slatted wood shelving or wire mesh shelving or a combination of both or no shelving, results were acceptable. In each test, sprinkler water demand, ceiling level temperatures, and extent of fire damage were all kept well within desirable test criteria limits.

Solid Shelving Test

The substitution of solid wood shelving in Test 4, which otherwise repeated the acceptable Test 1 with slatted wood shelving, produced an unacceptable result: excessive fire spread. The solid wood shelving promoted lateral fire spread and obstructed sprinkler discharge to the lower storage tiers. Since the limits of the main array were reached, a longer array would have resulted in further fire spread and consequently additional sprinkler openings.

Draft Curtain Tests

Test 6 and Test 7 were repeats of accept-

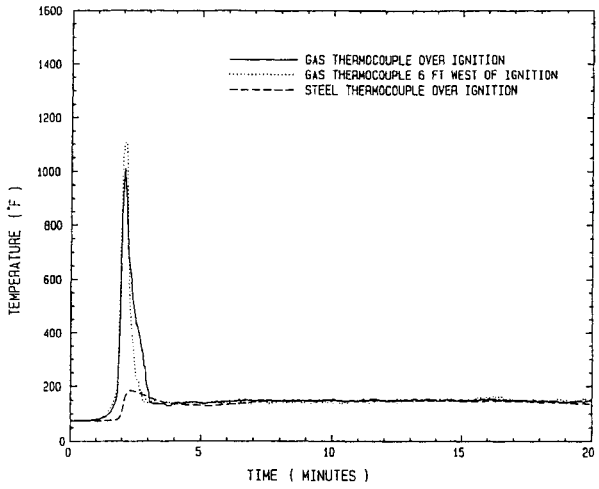


Figure 8. Peak Near-Ceiling Gas and Steel Temperatures - Test 1.

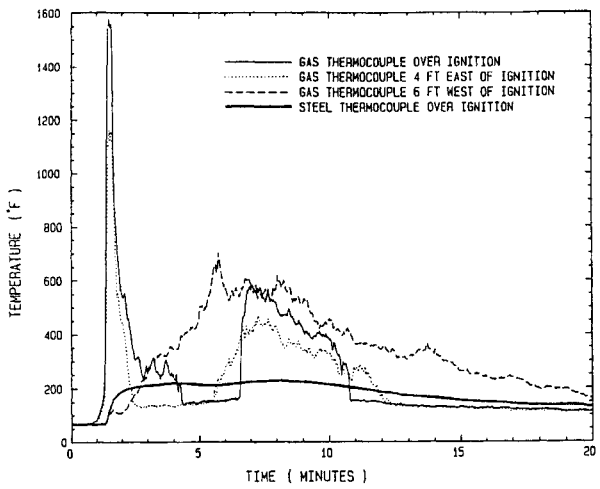
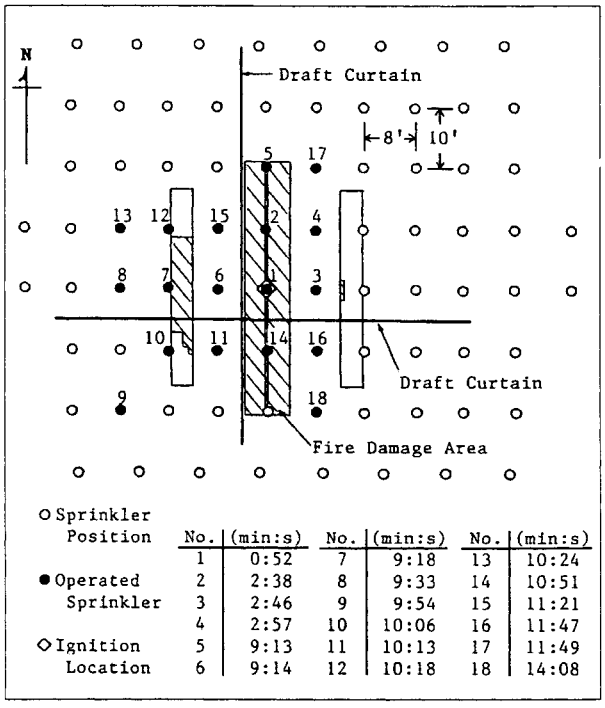


Figure 9. Peak Near-Ceiling Gas and Steel Temperatures - Test 6.

able tests (Test 1 and Test 3, respectively), except for the installation of draft curtains. The tests were characterized by one or more unacceptable results, including high water demands and excessive fire spread. The draft curtains, which were located close to each fire origin, caused more severe fires to develop: more sprinklers opened; the sprinkler opening patterns were atypical; distorted discharge patterns affected pre-wetting of commodity; fire spread and fuel consumption increased; and more smoke was produced.



No.	(min:s)	No.	(min:s)	No.	(min:s)
1	0:52	7	9:18	13	10:24
2	2:38	8	9:33	14	10:51
3	2:46	9	9:54	15	11:21
4	2:57	10	10:06	16	11:47
5	9:13	11	10:13	17	11:49
6	9:14	12	10:18	18	14:08

Figure 10. Sprinkler Operations and Overall Extent of Fire Damage - Test 7.

CONCLUSIONS

Specific Conclusions

1. A ceiling only sprinkler system design utilizing Extra Large Orifice, 0.64 in (16 mm) orifice diameter, sprinklers supplying a 0.60 gpm/ft^2 (24 mm/min) discharge density over a 2000 ft^2 (186 m^2) area will adequately protect Cartoned Group A Unexpanded Plastic commodities and lower fire hazard class commodities displayed up to a height of 20 ft (6.1 m) in warehouse retail stores with ceiling heights up to 27 ft (8.2 m) *provided* all guidelines for display and protection specified in the test program technical report[1] are observed. Guidelines include: minimum 7.5 ft (2.3 m) wide aisles; 6 in (15 cm) longitudinal flues dividing double-row racks; minimum 3 in (8 cm) transverse flues separating storage blocks; maximum 10 ft (3 m) rack bay length; and slatted wood shelving (if utilized) installed with minimum 2 in (5 cm) gaps with 6 in (15 cm) slats in conjunction with wire mesh top tier shelving.

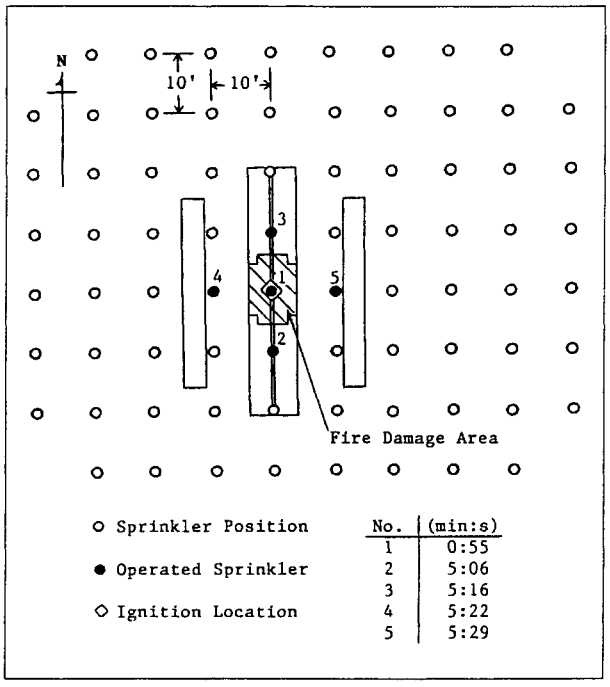


Figure 11. Sprinkler Operations and Overall Extent of Fire Damage - Test 8.

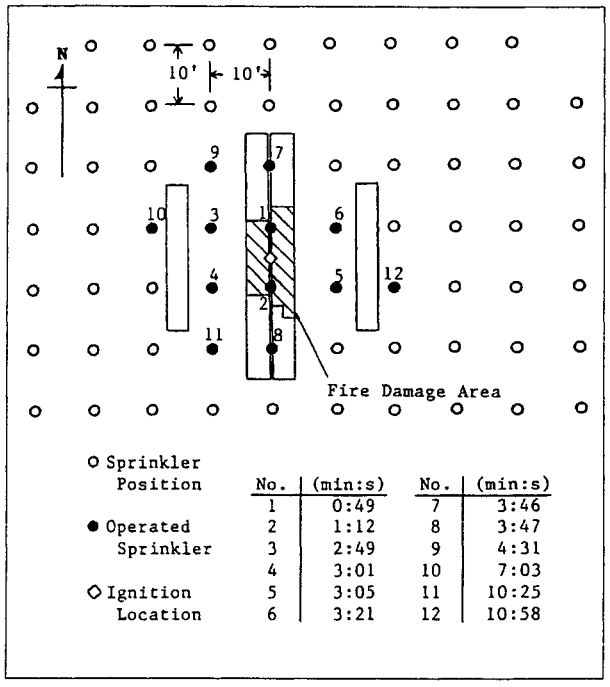


Figure 12. Sprinkler Operations and Overall Extent of Fire Damage - Test 9.

2. A discharge density of 0.50 gpm/ft^2 (20 mm/min) may be utilized under the following conditions: 286 °F (141 °C) rated sprinklers are installed; maximum storage height is 19 ft (5.8 m); maximum building height is 25 ft (7.6 m); minimum 9.5 ft (2.9 m) wide aisles are maintained; Conclusion 1 flues and rack bay size limits are maintained; and only open wire mesh shelving (if utilized) is installed.

3. A discharge density of 0.45 gpm/ft^2 (18 mm/min) may be utilized under the following conditions: 286 °F (141 °C) rated sprinklers are installed; maximum storage height is 14 ft (4.2 m); maximum building height is 22 ft (6.7 m); minimum 7.5 ft (2.3 m) wide aisles are maintained; Conclusion 1 flues and rack bay size limits are maintained; and only open wire mesh shelving (if utilized) is installed.

General Conclusions

1. Tests conducted to investigate the performance of two different sprinkler temperature ratings were inconclusive.

2. The solid wood shelving used in one test promoted horizontal fire spread and obstructed sprinkler discharge.

3. Test results indicated that draft curtains were detrimental to sprinkler performance in sprinklered warehouses and warehouse retail stores. To further understand the effects on sprinkler performance caused by the presence of draft curtains, additional testing should be considered.

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