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# COMPARISON OF EUROPEAN CONVENTIONAL AND U.S. SPRAY SPRINKLERS

by

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## SUMMARY

Twelve large-scale fire tests were conducted to compare the fire protection performances of selected European conventional style and U.S. spray sprinklers. Two different fire test scenarios were investigated. The assessment of sprinkler effectiveness was based upon total numbers of sprinkler operations and resulting fire damage to the fuel arrays. Using these criteria, both European conventional-style sprinklers and U.S. spray sprinklers provided control of fires for the scenarios in which they were evaluated. However, there were differences in the levels of protection provided. In general, the spray sprinklers provided better fire protection than European conventional-style sprinklers under identical test conditions. In tests involving high-challenge plastic commodity fires, the spray sprinklers provided significantly better fire protection. For moderate-to-high challenge commodity fires involving a simulated noncombustible product in cardboard cartons, the relative performance of the two types of sprinklers depended upon the ignition location relative to overhead sprinklers.

## INTRODUCTION

The automatic sprinklers used in the United States from 1878 until the early 1950s were designed to project approximately half of the water upward toward the ceiling and the remaining half downward. These sprinklers could be installed in either upright or pendent position and provided protection against roof involvement during fires.

Attempts to reduce fire protection costs resulted in the development of the spray sprinkler, which was introduced in 1952. This sprinkler was designed to project all of the discharging water downward and outward, creating a parabolic (umbrella) spray pattern with the deflector at the vertex of the pattern. The rationale was to effect early fire control by directing all of the available water to the likeliest fire source locations, *i.e.*, at the floor level. Gaining early fire control would therefore obviate the need to protect the ceiling against fire involvement. The newly developed sprinklers would also provide fine water droplets, or spray, which would cool the ceiling gases and prevent roof involvement during a fire.

In 1958, after several years of successful application, the spray sprinkler was designated as the standard sprinkler in the United States, and the early generation sprinklers were classified as "old-style" sprinklers. The old-style sprinklers were gradually phased out of use in the United States.

However, old-style sprinklers, with their ceiling protection philosophy, continued to find application in Europe, where they were referred to as "conventional style" sprinklers. The conventional style sprinkler is still preferred over the spray sprinkler in Europe. Recently, questions have been raised regarding the relative merits of the two types of sprinklers in providing effective fire protection.

The objective of this paper is to compare the fire protection performance of U.S. spray sprinklers and European conventional style sprinklers in selected large-scale rack storage fire tests. Tests were categorized into two series: Series I and Series II. Test Series 1 considered sprinkler performance in

* To receive communication

**Table 1.**

**Ignition location and sprinkler characteristics: Series I**

| Test No. | Ignition Configuration | Sprinkler** | Type | Temperature Rating (°C) | RTI* ($m^{1/2}s^{1/2}$) | K Factor (*l*/min/bar$^{1/2}$) |
|---|---|---|---|---|---|---|
| 1 | Below 1 | Conventional (15 mm) | Glass Bulb | 68 | 232 | **81** |
| 2 | Below 1 | Spray (15 mm) | Soldered Link | 74 | 218 | **81** |
| 3 | Below 2 | Conventional (15 mm) | Glass Bulb | 68 | 232 | **81** |
| 4 | Below 2 | Spray (15 mm) | Soldered Link | 74 | 218 | **81** |

* Apparent RTI. Measured without consideration of conduction effects.
** Sprinkler orifice diameters are nominal values. Nominal 15 mm conventional is equivalent to nominal 1/2 in. spray.

fire tests involving a plastic commodity stored 3 m high under a 9.1 m high ceiling. The fuel used in Test Series II was a simulated non-combustible product in cardboard cartons stored 6.1 m high, also under a 9.1 m high ceiling.

In these tests, the performances of spray and conventional style sprinklers were compared under identical sprinkler installation and water discharge conditions. The degree of fire control was judged on the basis of the total number of sprinkler operations, fire damage to fuel arrays, and maximum ceiling gas and steel temperatures over ignition. The fires were judged to have been controlled by the sprinkler system if: 1) *fire damage* did not extend to the end of the arrays - involvement of the target arrays is allowed, but target array fire damage also must not extend to the end of the arrays or extend through an array to the back face; and 2) the *ceiling steel temperature* over ignition remains below 638°C throughout the test period. The *total water demand* was also used as a criterion to judge fire control for these tests. The total water demand was used as a comparative measure of sprinkler system performance for those cases where U.S. spray and European conventional sprinklers were evaluated under the same initial test conditions.

## Test Setups

All tests were conducted in a large-scale test facility having a 9.1 m floor-to-ceiling height. Ninety-six (96) sprinklers were installed on 3 m x 3 m spacing over the test area using nominal 2 in. diameter piping. Sprinklers were installed in upright position with deflectors 0.2 m below the ceiling. A summary of conditions for Series I tests is presented in Table 1. Four fire tests are included in this series. Tests 1 and 3 evaluated the performance of a European conventional sprinkler. The ignition location was positioned directly under a sprinkler in Test 1 and centered below two sprinklers in Test 3. The results of these tests were compared with the performance of a standard spray sprinkler in Tests 2 and 4 using the same two ignition configurations.

A summary of test conditions for Series II tests is presented in Table 2. Eight large-scale tests comprised this series. Four types of sprinklers were evaluated using two ignition configurations. Tests were performed with ignition centered either directly below a sprinkler (Tests 5-8) or below four sprinklers (Tests 9-12).

## Test Series I: Plastic Commodity Tests

The fuel arrangement for Series I tests is shown in Figures 1 and 2. The fuel used in these tests was a plastics-in-cardboard carton commodity. Each carton was 53.3 cm x 53.3 cm x 50.8 cm high and designed to hold 125 473-ml-capacity polystyrene plastic cups. The average weight of a single carton was 6.4 kg. Fifty-seven percent of the weight, *i.e.*, 3.6 kg, was the plastic cups; the remaining 2.8 kg was the carton and its internal cardboard dividers. Eight cartons were placed in a 2 x 2 x 2 stack upon a 106.7 cm x 106.7 cm x 12.7 cm wood pallet. The wood pallets weighed between 23.1 and 24.0 kg each. Pallets of the commodity were stored 3.1 m high in steel racks as shown in Figure 1.

The test arrangement consisted of a primary array, in which ignitors were placed, and two target arrays. The primary fuel array was eight pallets long by two pallets deep by two tiers high. Each target array was six pallets long by one pallet deep by two tiers high and was located across a 2.4 m aisle space on either side of the primary fuel array (Figure 2). The clearance from the top of the fuel arrays to the ceiling was 6.0 m.

In these tests, the bottom tier of pallets was elevated from the floor to increase air access and provide a worst case condition. The 0.4 m elevation spacing was selected to allow sufficient clearance for use of a weighing platform under the ignition array for mass loss measurements. This clearance is consistent with that used in previous rack storage test programs conducted at FMRC.

Ignition was centered at the base of the bottom tier of the primary fuel array. The ignition source consisted of four 76 mm long by 76 mm diameter cellu-cotton rolls, each

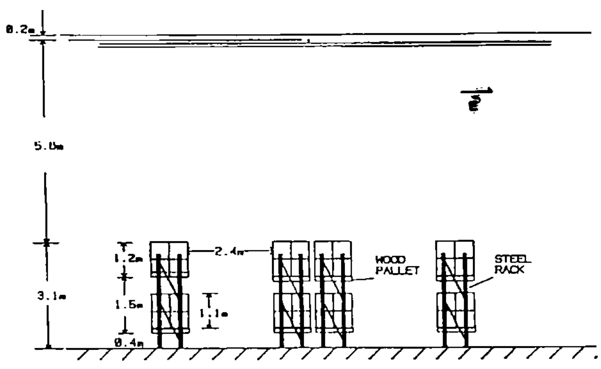

Figure 1. Fuel arrangement for Series I Tests (elevation view).

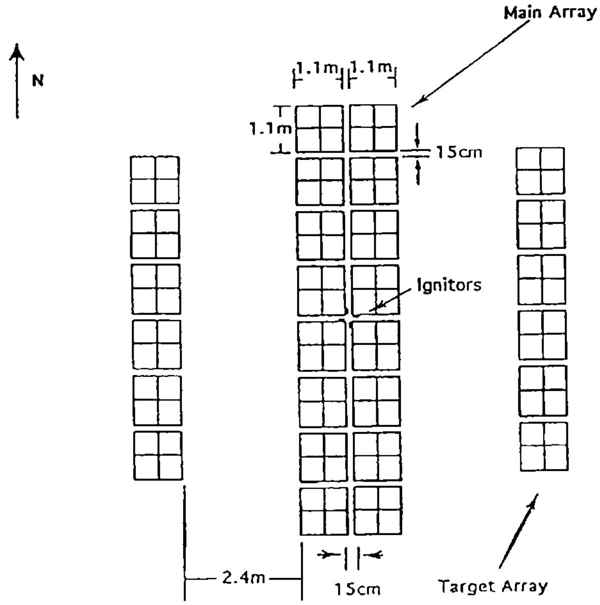

Figure 2. Fuel arrangement for Series I Tests (plan view).

**Table 2.**

**Ignition location and sprinkler characteristics: Series II**

| Test No. | Ignition Configuration | Sprinkler** | Type | Temperature Rating (°C) | RTI* ($m^{1/2}s^{1/2}$) | K Factor ($l$/min/bar$^{1/2}$) |
|---|---|---|---|---|---|---|
| **5** | Below 1 | Conventional (15 mm) | Soldered Link | 74 | 144 | 81 |
| **6** | Below 1 | Spray (15 mm) | Soldered Link | 74 | 144 | 81 |
| **7** | Below 1 | Conventional (20 mm) | Soldered Link | 74 | 144 | 115 |
| **8** | Below 1 | Spray (20 mm) | Soldered Link | 74 | 144 | 115 |
| **9** | Below 4 | Conventional (15 mm) | Soldered Link | 74 | 144 | 81 |
| **10** | Below 1 | Spray (15 mm) | Soldered Link | 74 | 144 | 81 |
| **11** | Below 1 | Conventional (20 mm) | Soldered Link | 74 | 144 | 115 |
| **12** | Below 1 | Spray (20 mm) | Soldered Link | 74 | 144 | 115 |

* Apparent RTI. Measured without consideration of conduction effects.
** Sprinkler orifice diameters are nominal values. Nominal 15 mm conventional is equivalent to nominal 1/2 in. spray.

soaked with 118 ml of gasoline and wrapped in a polyethylene plastic bag. The fuel array was positioned so that the ignition location relative to overhead sprinklers was either directly under a sprinkler or centered below two sprinklers.

The conventional sprinkler tested in this series had a nominal 15 mm* diameter orifice with a K-factor** of 81 $l$/min/bar$^{1/2}$. It was approved by the Loss Prevention Council (LPC) of Great Britain. The actuation mechanism was a glass bulb nominally rated at 68°C. The Response Time Index (RTI), a quantitative measure of sprinkler response characteristics[1,2], as determined by the FMRC Plunge Test was 232 m$^{1/2}$ s$^{1/2}$. This RTI value was measured without consideration of conductive heat losses by the sprinkler actuation link to sprinkler frame, fittings and piping. According to Heskestad and Bill[3], conduction effects are important for small and slow-developing fires which produce low ceiling gas temperatures and velocities. Due to the rapid-developing nature of the fires characteristic of the fuel arrays tested, it was judged that the conduction effect would be small for these tests. The conduction factor was, therefore, not determined for sprinklers used in these fire tests.

The spray sprinkler evaluated was a fusible link type rated at 74°C with an RTI of 218 m$^{1/2}$ s$^{1/2}$ and K-factor of 81 $l$/min/bar$^{1/2}$. Again, conduction effects were not considered when determining the RTI for this sprinkler. The sprinkler was Approved by Factory Mutual Research Corporation (FMRC) and listed by Underwriters Laboratories (UL).

For Series I tests, the sprinkler system was set to discharge at a constant pressure of 4.6 bar. At this pressure each sprinkler discharged 170 $l$/min. With sprinklers installed on 3 m x 3 m spacing, the design application density was 18 mm/min.

## Test Series II: Noncombustibles in Cardboard Cartons

The fuel arrangement for Series II tests is shown in Figures 3 and 4. It consisted of a 6.1 m high rack storage of a simulated noncombustible product in cardboard cartons. Each carton was double-walled and had dimensions of 106.7 cm x 106.7 cm x 106.7 cm. Carton walls were constructed of three layers of corrugated cardboard. Inside each carton was a 22 gage (0.8 mm) sheet-metal liner. Each carton was placed upon a 106.7 cm x 106.7 cm x 12.7 cm wood pallet and

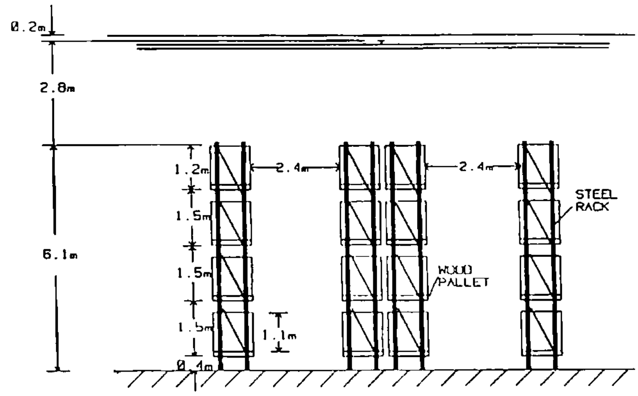


Figure 3. Fuel arrangement, Series II (elevation view).

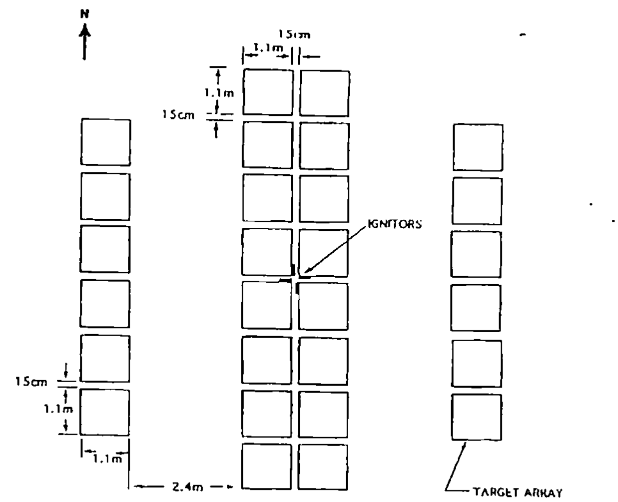


Figure 4. Fuel arrangement, Series II (plan view).

* This (15 mm) is the metric designation for the orifice size equivalent to a nominal 1/2 in. diameter sprinkler. Metric designations for nominal 3/8 in. and 17/32 in. diameter orifice sizes are nominal 10 mm and 20 mm respectively. See Reference 4.

** The K-factor is a number indicating sprinkler nozzle discharge capacity, # defined as K=Q/ p, where Q is the water discharge rate and p is the sprinkler discharge pressure. Units are $l$/min/bar stored in double row steel racks. The average carton weight was 61.2 kg. Sixty-two percent, *i.e.*, 37.9 kg, of the weight was the corrugated cardboard carton and the remaining 23.3 kg was the metal liner. The wood pallets were the same as those used in Series I tests.

The test arrangement consisted of a primary array, containing the ignition source, and two target arrays spaced across 2.4 m aisles (Figure 4). The primary array was eight pallets long by two pallets deep by four tiers high.

Target arrays were six pallets long by one pallet deep by four tiers high. There was a 3 m clearance from the top of the fuel arrays to the ceiling.

The source of ignition was four ignitors of the same type as those used in Series I tests. These were centered at the base of the bottom tier within the primary fuel array. In these tests, the ignition location relative to overhead sprinklers was either directly under a sprinkler or centered below four sprinklers.

Four different sprinklers were tested: two U.S. spray sprinklers and two European conventional style sprinklers. Nominal orifice diameters were either 15 mm or 20 mm. All sprinklers were produced by the same manufacturer and were as follows:

(1) Large-orifice conventional type: Overall height 79 mm and nominal 20 mm diameter orifice;
(2) Standard-orifice conventional type: Overall height 68 mm and nominal 15 mm diameter orifice;
(3) Large-orifice spray type: Overall height of 76 mm and nominal 20 mm diameter orifice; and
(4) Standard-orifice spray type: Overall height of 66 mm and nominal 15 mm diameter orifice.

All sprinklers tested had the same soldered link actuation mechanism. The actuation mechanism had a nominal 74°C temperature rating. The sprinklers had an RTI value of approximately 144 $m^{1/2} s^{1/2}$ as determined by the FMRC Plunge Test. The RTI value was determined without consideration of conduction effects. The spray sprinkler was FMRC-Approved and Underwriters Laboratories (UL) listed. The conventional style sprinkler was Approved by the Loss Prevention Council (LPC) of Great Britain and UL listed. For these tests the sprinkler system was set to discharge at a constant pressure of 3.1 bar for nominal 15 mm diameter sprinklers and 1.4 bar for the nominal 20 mm diameter sprinklers. At these pressures, sprinklers discharged 140 *l*/min each. This provided a design application density of 15 mm/min for the 3 m x 3 m sprinkler spacing used in these tests.

## INSTRUMENTATION

Figures 5, 6 and 7 present instrumentation layouts for the three ignition configurations tested.

Sprinkler actuation times were determined by wiring electrical circuits to include the sprinkler frame and link mechanism. When the sprinkler actuated, ejecting the link, the circuit was broken and the time recorded by the computer data acquisition system.

To determine ceiling gas temperatures, 28-gage (0.3 mm diameter) chromel-alumel wire thermocouples were placed at 27 selected sprinkler locations over the test area. The thermocouples were positioned 0.2 m down from the ceiling at the elevation of the sprinkler links. In tests in which the ignition location was not directly under a sprinkler, a thermocouple was installed at the ceiling directly over ignition at 0.2 m down from the ceiling.

Potential damage to ceiling structural steel members was assessed by monitoring the temperature of 1.2 m long sections of steel angle (51 mm x 51 mm x 6.4 mm thick) installed at two ceiling locations over the ignition area. Each steel angle had two 20-gage chromel-alumel thermocouples embedded

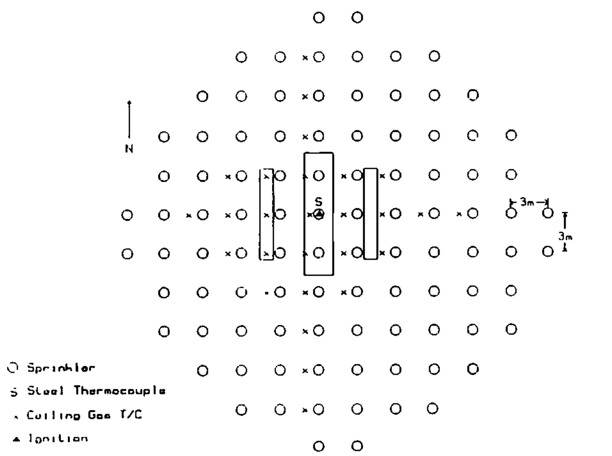


Figure 5. Instrumentation plan. Ignition directly under one sprinkler.

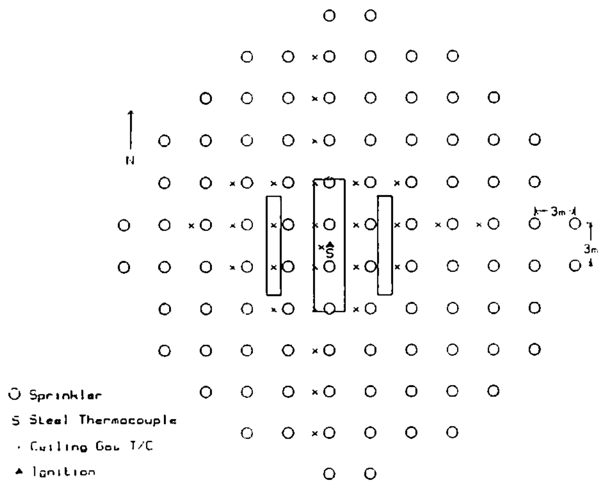


Figure 6. Instrumentation plan. Ignition centered below two sprinklers.

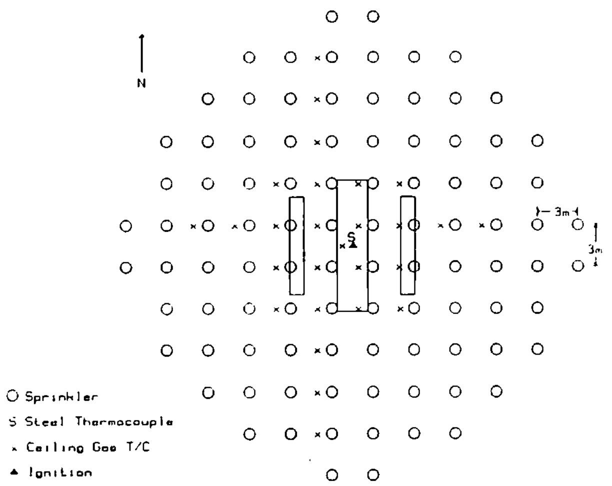


Figure 7. Instrumentation plan. Ignition centered below four sprinklers.

in the steel for temperature measurement. These sections of steel angle were installed with one flat surface in direct contact with the ceiling. For each test, one section of steel angle was located directly over ignition; the other was located 3 m directly west of ignition.

Relative fire sizes at first sprinkler actuation could be estimated for these tests by measuring mass loss and determining mass burning rates. These data were consulted in one case in which test outcomes were in question. Mass loss measurements were made using a 2.4 m x 2.4 m weighing platform constructed of steel I-beams covered with gypsum board and steel sheathing. The platform rested upon four load cells, one at each corner.

## Results

In all twelve tests evaluated for this study, fires were prevented from spreading horizontally to the ends of the fuel arrays. However, the maximum allowable ceiling steel temperature of 638°C was exceeded in two tests. The application of the three fire control criteria, *i.e., total water demand, fire damage*, and *ceiling steel temperature* over ignition, did reveal some distinct differences in the level of protection provided by European conventional style and U.S. spray sprinklers.

### Test Series I: Plastic Commodity Tests

Four plastic commodity tests were conducted. A European conventional style sprinkler was compared with a spray sprinkler for cases in which ignition was located directly below a sprinkler (Tests 1 and 2) and centered below two sprinklers (Tests 3 and 4). Sprinkler performance and test data summaries for Series I tests are presented in Tables 3 and 4.

In Tests 1 and 2, with ignition directly below a sprinkler, the ceiling gas and steel temperature measurements directly over ignition were not representative indicators of the actual severity of the fires during tests. This is because the thermocouples over ignition were wetted by water spray upon first sprinkler actuation. Sprinkler performance for this ignition configuration was assessed by comparing the total number of sprinkler operations and the resulting fire damage to the fuel arrays. There were 42 sprinkler operations for a total water demand of 7,154 *l* per minute in Test 1 when the conventional sprinkler was used, as compared with 29 sprinkler operations or 4,939 *l* per minute for the spray sprinkler used in Test 2. The equivalent of 30 pallets of fuel, *i.e.*, 54 percent of the available fuel, was consumed when the conventional sprinkler was used in Test 1. The damage allowed by the spray sprinkler in Test 2 was just 15 pallets, or 27 percent of the available fuel consumed. Limited fire involvement of target arrays occurred in both tests.

The ceiling protection advantage of the European conventional sprinkler is clearly demonstrated by the comparison of Tests 3 and 4, which show sprinkler system marginal control of a high-challenge fire. With ignition centered below two sprinklers in Tests 3 and 4, the ceiling gas and steel thermocouples located directly over ignition were not contacted by the sprinkler spray and therefore temperature measurements were higher overall than in the first two tests. The ceiling gas temperatures measured over ignition at first sprinkler actuation in Tests 3 and 4 were 399°C and 435°C, respectively. The maximum ceiling gas temperatures were 1017°C in Test 3 using the conventional sprinkler, and 1046°C for Test 4 when the spray sprinkler was used. The conventional sprinkler also maintained lower ceiling steel temperatures with a maximum of 512°C in Test 3, as compared with 652°C in Test 4 using the spray sprinkler. A ceiling steel temperature in excess of 538°C for more than 10 minutes or a maximum temperature of 638°C for any time duration is considered a potential threat

**Table 3**

**Sprinkler Performance: Series I Tests**

| Test No. | Ignition Configuration | Sprinkler | Sprinkler Actuation Time (Mins) 1st | 2nd | Last | Total | Total Discharge (*l*/min) |
|---|---|---|---|---|---|---|---|
| 1 | Below 1 | Conventional (15 mm) | 1:05 | 2:10 | 7:11 | 42 | 7,154 |
| 2 | Below 1 | Spray (15 mm) | 0:55 | 1:47 | 7:03 | 29 | 4,939 |
| 3 | Below 2 | Conventional (15 mm) | 1:16 | 1:22 | 12:55 | 43 | 7,324 |
| 4 | Below 2 | Spray (15 mm) | 0:55 | 1:07 | 8:49 | 26 | 4,428 |

* Sprinkler orifice diameters are nominal values.

**Table 4**

**Temperature and Fire Damage Data: Series I Tests**

| Test No. | Sprinkler* | Temperature (°C) At 1st** | Maximum*** Gas | Steel | Array Damage | Aisle Jump |
|---|---|---|---|---|---|---|
| 1 | Conventional (15 mm) | 270 | — | 53 | 54% | Yes |
| 2 | Spray (1/2 in.) | 277 | — | 84 | 27% | Yes |
| 3 | Conventional (15 mm) | 399 | 1017 | 512 | 42% | Yes |
| 4 | Spray (1/2 in.) | 435 | 1046 | 652 | 20% | No |

* Sprinkler orifice diameters are nominal values.
** Ceiling gas temperature at 1st sprinkler actuation.
*** Maximum gas and steel temperatures measured directly over ignition. In Tests 1 and 2, with a sprinkler over ignition, maximum ceiling gas and steel temperatures occurred at around time of first sprinkler actuation.

to structural steel members and is likely to cause structural failure[5, 6]. During Test 4 the steel temperature over ignition peaked at 652°C and was above 538°C for approximately 5 minutes. The sprinklers therefore failed to provide adequate fire control in this test.

However, the total numbers of sprinkler operations and fire damage to the fuel array were again higher for the conventional sprinkler than for the spray sprinkler. In Test 3 there were 43 conventional sprinkler operations compared with 26 spray sprinkler operations in Test 4. Total water demands were 7,324 and 4,428 liters per minute, respectively, for Test 3 and Test 4.

In Test 3 the equivalent of 24 pallets of fuel (42 percent) was consumed. Only 11 pallets (20 percent) were consumed when the spray sprinkler was used in Test 4. The conventional sprinkler also allowed the fire to spread to the target arrays. Because of the steel temperature criterion, Test 4 was considered a failure even though the fire was actually worse in Test 3.

The results of these large-scale high-challenge fire tests indicate that the spray sprinkler provided better fire control while the European conventional-style sprinklers provided improved ceiling protection, but only for the case in which ignition was centered below two sprinklers. A significant difference in maximum steel temperatures was not evident with ignition directly below a sprinkler, as in Tests 1 and 2, since both sprinklers effectively shielded the steel temperature measurement location.

It appears that for these high-challenge fires, the use of sprinkler water for ceiling protection negatively affects fire control.

## Series II: Noncombustibles in Cardboard Cartons

With this fuel package, the relative performances of the two types of sprinklers appeared to be largely dependent upon the ignition configuration. Sprinkler performance summaries for Series II tests are presented in Tables 5 and 6.

When ignition was centered directly below a sprinkler, the standard orifice (nominal 1/2 in. diameter) conventional and spray sprinklers performed at a comparable level, requiring 37 and 36 sprinkler operations, or 5,182 *l* per minute and 5,042 *l* per minute, respectively, in Tests 5 and 6. Use of the conventional sprinkler in Test 5 resulted in slightly less fire damage to the fuel arrays with the equivalent of 34 pallets consumed, *i.e.*, 30 percent of the available fuel, as compared with 44 pallets or 39 percent of the available fuel consumed when the spray sprinkler was used in Test 6. The conventional sprinkler also prevented involvement of the target arrays.

The large-orifice (nominal 17/32 in. diam-

**Table 5**

**Sprinkler Performance: Series II Tests**

| Test No. | Ignition Configuration | Sprinkler* | Sprinkler Actuation Time (Mins) 1st | 2nd | Last | Total | Q *l*/min |
|---|---|---|---|---|---|---|---|
| 5 | Below 1 | Conventional (15 mm) | 0:57 | 4:03 | 15:03 | 37 | 5,182 |
| 6 | Below 1 | Spray (15 mm) | 1:23 | 2;30 | 11:23 | 36 | 5,042 |
| 7 | Below 1 | Conventional (20 mm) | 0:55 | — | — | 1 | 140 |
| 8 | Below 1 | Spray (20 mm) | 1:29 | 2:17 | 16:14 | 35 | 4,902 |
| 9 | Below 4 | Conventional (20 mm) | 1:12 | 1:15 | 14:04 | 38 | 5,322 |
| 10 | Below 4 | Spray (15 mm) | 1:23 | 1:24 | 1:26 | 4 | 560 |
| 11 | Below 4 | Conventional (20 mm) | 1:04 | 1:07 | 8:11 | 49 | 6,862 |
| 12 | Below 4 | Spray (20 mm) | 1:02 | 1:05 | 1:13 | 4 | 560 |

* Sprinkler orifice diameters are nominal values.

**Table 6**

**Temperature and Fire Damage Data: Series II Tests**

| Test No. | Sprinkler* | Temperature At 1st | Temperature Maximum** Gas | Temperature Maximum** Steel | Array Damage | Aisle Jump |
|---|---|---|---|---|---|---|
| 5 | Conventional (15 mm) | **338** | — | 56 | 30% | **No** |
| 6 | Spray (15 mm) | **363** | — | 122 | 39% | **Yes** |
| 7 | Conventional (20 mm) | **329** | — | 36 | 3% | **No** |
| **8** | Spray (20 mm) | **311** | — | 70 | 24% | **No** |
| 9 | Conventional (20 mm) | **599** | 912 | 743 | 24% | **No** |
| 10 | Spray (15 mm) | **577** | 704 | 76 | 3% | **No** |
| 11 | Conventional (20 mm) | **585** | 860 | 466 | 26% | **No** |
| **12** | Spray (20 mm) | **549** | **733** | 77 | 4% | **No** |

* Sprinkler orifice diameters are nominal values.
** Maximum gas and steel temperatures measured directly over ignition. In Tests 5 and 8, with a sprinkler over ignition, maximum ceiling gas and steel temperatures occurred at around time of first sprinkler actuation.

eter) conventional sprinkler used in Test 7 controlled the fire with just one sprinkler operation (140 $l$ per minute) compared with 35 sprinkler operations (4,902 $l$ per minute) required for the large-orifice spray sprinkler used in Test 8.

The fire was controlled so quickly in Test 7 that just four pallets, or 3 percent of the available fuel, were damaged by the fire, as compared to the equivalent of 26 pallets consumed (24 percent) in Test 8 when the spray sprinkler was used. The target arrays were not involved in either test. At the time of first sprinkler actuation, the mass burning rate* in Test 7 (conventional sprinkler) was 0.32 kg/s with 5.0 kg of fuel consumed. In Test 8, the burning rate was 0.36 kg/s at first sprinkler actuation and 5.6 kg of the fuel had been consumed. Upward gas velocities directly over ignition, measured 0.2 m down from the ceiling, were approximately 2.7 m/s at the time of first sprinkler actuation in both Test 7 and Test 8. These measurements indicate that the fires in Tests 7 and 8 presented equivalent challenges to the sprinkler systems and the difference in sprinkler performance was therefore a function of sprinkler characteristics.

* Time averaged value for 10 s time interval immediately preceding first sprinkler actuation.

When the ignition location was centered below four sprinklers (Tests 9-12), the spray sprinklers proved superior. The use of spray sprinklers resulted in faster fire control, fewer sprinkler operations and lower ceiling gas and steel temperatures. The spray sprinklers also confined fire damage to less than 4 percent of the available fuel consumed, as compared with an average of 25 percent when the conventional style sprinklers were used.

With nominal 1/2 in. diameter orifice sprinklers (Tests 9 and 10), the maximum ceiling gas temperature over ignition was 912°C for the conventional style sprinkler and 704°C for the spray sprinkler. The difference between ceiling steel temperatures was even more significant. Maximum ceiling steel temperatures were 743°C for the conventional sprinkler and 76°C for the spray sprinkler. In Test 9, the conventional sprinkler allowed the ceiling steel temperature to exceed the maximum allowed temperature of 538°C, and this measurement was in excess of 538°C for nearly 10 minutes. Such an exposure constitutes a ceiling damage potential. In Test 9 there were 38 operations for a total water demand of 5,322 $l$ per minute for conventional sprinklers, compared with just four spray sprinkler opera-

**Table 7**

**Test results: fire control assessment**

| Test No. | Sprklr. | K | RTI | Ignition Below | Max. Temp. (C) Gas | Steel | No. Sprklrs. | Total Flow | Percent Damage | Control (Y/N) |
|---|---|---|---|---|---|---|---|---|---|---|
| Series I | | | | | | | | | | |
| 1 | CS | 81 | 232 | ONE | 270 | 53 | 42 | 7154 | 54 | Y |
| 2 | SS | 81 | 218 | ONE | 277 | 84 | 29 | 4939 | 27 | Y |
| 3 | CS | 81 | 232 | TWO | 1017 | 512 | 43 | 7324 | 42 | Y |
| 4 | SS | 81 | 218 | TWO | 1046 | 652* | 26 | 4428 | 20 | N |
| Series II | | | | | | | | | | |
| 5 | CS | 81 | 144 | ONE | 338 | 56 | 37 | 5182 | 30 | Y |
| 6 | SS | 81 | 144 | ONE | 363 | 122 | 36 | 5042 | 39 | Y |
| 7 | CS | 115 | 144 | ONE | 329 | 36 | 1 | 140 | 3 | Y |
| 8 | SS | 115 | 144 | ONE | 311 | 70 | 35 | 4902 | 24 | Y |
| 9 | CS | 81 | 144 | FOUR | 912 | 743* | 38 | 5322 | 24 | N |
| 10 | SS | 81 | 144 | FOUR | 704 | 76 | 4 | 560 | 3 | Y |
| 11 | CS | 115 | 144 | FOUR | 860 | 466 | 49 | 6862 | 26 | Y |
| 12 | SS | 115 | 144 | FOUR | 733 | 77 | 4 | 560 | 4 | Y |

* Temperature exceeds 638°C maximum temperature used as criterion for assessing ceiling structural steel damage potential.

Note 1: CS - Conventional European Type Sprinkler.
SS - Spray Sprinkler.

Note 2: Nominal 15 mm sprinkler has K Factor of 81 ($l$/min/bar$^{1/2}$).
Nominal 20 mm sprinkler has K Factor of 115 ($l$/min/bar$^{1/2}$).

Note 3: Total flow is in liters per minute.

tions or 560 *l* per minute total water demand during Test 10.

There were similar performance differences with the nominal 17/32 in. diameter large-orifice sprinklers evaluated in Tests 11 and 12. Maximum ceiling gas temperatures were 860°C for the conventional and 733°C for the spray sprinkler. A larger discrepancy existed for maximum ceiling steel temperatures, which were 466°C for the conventional and 77°C for the spray sprinkler. The 17/32 in. conventional sprinkler used in Test 11 had the highest number of sprinkler operations of all tests conducted for this study. There were 49 operations, or 6,862 *l* per minute total water demand in Test 11, compared to just four spray sprinkler operations or 560 *l* per minute total water demand, during Test 12.

The poor performance of the conventional style sprinklers for the case in which ignition was centered below four sprinklers in Tests 9 and 11 can possibly be attributed to the localization of water in the space below the deflector observed in Tests 5 and 7. When ignition was directly below the sprinkler, as in Tests 5 and 7, the extra water, coupled with the large drops falling from the ceiling, achieved better penetration of the fire plume. The result was improved fire control. However, when ignition was centered below four sprinklers, this localization of water was of little use since none of the four sprinklers were directly over the fire source location.

## Conclusions

A comprehensive Test Summary is presented in Table 7. Based upon the results of these tests, the following conclusions are offered:

1. The European conventional style and U.S. spray sprinklers selected for this program controlled fires in 10 of the 12 tests according to the criteria used in assessing

fire control, *i.e.*, the total water demand, fire damage, and the maximum ceiling steel temperature over ignition. In the remaining two tests, the total water demand and fire damage were within the limits set by the respective criteria; however, ceiling steel temperatures were excessive. One of these tests involved a U.S. spray sprinkler; the other involved use of a European conventional style sprinkler.

2. In four of six direct comparison tests, spray sprinklers provided better overall fire control performance according to the evaluation criteria used. Of the two remaining direct comparisons, the European conventional sprinkler performed marginally better in one case and was clearly superior in the other. In five of the six direct comparisons, the total water demand was less for U.S. spray sprinklers than for the European conventional sprinklers.

3. In direct comparisons in which ignition was either directly below a sprinkler or centered below two sprinklers with a large ceiling clearance (6 m), the European conventional style sprinklers provided better cooling of the ceiling steel that was located directly over ignition. However, with ignition centered below four sprinklers with 3 m ceiling clearance, the spray sprinklers provided superior cooling of the ceiling steel as these sprinklers quickly controlled the fires with just four sprinkler operations.

4. For the high-challenge fires involving the 3 m high rack storage of a plastic commodity with a large ceiling clearance (Series I), the U.S. spray sprinklers tested provided better protection than the European conventional style sprinklers. There were significantly fewer spray sprinkler operations and less fire damage to the fuel arrays.

5. In the case of the high-challenge fire with ignition centered below two sprinklers (Series I, Tests 3 and 4), the conventional style provided better ceiling protection at the cost of less effective fire control. The system total water demand and fire damage were significantly higher than that allowed by the spray sprinkler.

6. For the moderate-to-high challenge high-piled rack storage of a simulated noncombustible product in cardboard cartons, sprinkler performance depended upon ignition location relative to overhead sprinklers. With ignition located directly below a sprinkler, the nominal 15 mm diameter orifice conventional style and spray sprinklers provided comparable fire protection. However, using the same ignition configuration, the large-orifice conventional style sprinkler (nominal 20 mm diameter) provided fire protection superior to that of the large-orifice spray sprinkler. This superior performance was attributed to the high density localization of water directly below the sprinkler in this test. When ignition was centered below four sprinklers, the spray sprinkler clearly provided better fire protection.

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