High Volume/Low Speed Fan and Sprinkler Operation

Phase II Research Program

Final Report

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THE FIRE PROTECTION RESEARCH FOUNDATION

Research in support of the NFPA mission

FIRE RESEARCH

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FOREWORD

High volume low speed (HVLS) fans are in increasing use in storage and manufacturing facilities. However, the interaction of these fans and automatic sprinkler operation is unknown. In order to inform spacing and other installation requirements in NFPA 13, *Standard for the Installation of Automatic Sprinklers*, the Foundation initiated a research comprehensive research program with two Phases.

This report describes Phase II research activities. It describes the evaluation of the effect of the HVLS fans upon the performance of both ESFR and CMDA sprinklers protecting both rack storage and palletized commodities. A total of 10 full-scale fire tests were conducted during the period of June through December of 2010. Comprehensive guidance for the use of the fans in the presence of sprinklered storage is presented.

The content, opinions and conclusions contained in this report are solely those of the authors.

THE FIRE PROTECTION RESEARCH FOUNDATION

Research in support of the NFPA mission

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Research Report

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Table of Contents

Table of Contents

Index of Tables

Table of Figures

EXECUTIVE SUMMARY

The objective of the Phase II research effort was to expand the investigation of the impact of High Volume/Low Speed (HVLS) fans on the performance of automatic sprinklers. Phase I addressed only HVLS fan impact on Early Suppression Fast Response (ESFR) sprinklers within rack storage array. Phase II included both ESFR and Control Mode Density Area (CMDA) sprinklers for rack and palletized storage arrays. Cartoned, unexpanded Group A plastic commodity was used for all tests.

Ten full-scale tests were completed, four tests in the Large Burn Lab of the Fire Laboratory at the FM Global Research Campus located in West Glocester, Rhode Island and six tests at the Underwriters Laboratories large scale fire test facility located in Northbrook, Illinois.

The HVLS fan used in nine of the ten tests was the MaxAir Whisperfoil XL (Model MA24XL2006) manufactured by MacroAir. This fan had six blades and was 24 feet in diameter. Performance data provided by MacroAir indicates the fan produced approximately 330,000 cfm at 63 rpm. The final test, conducted by XL GAPS, used the Rite-Hite Revolution 24-foot diameter, 4-blade, 48 RPM HVLS fan.

The ventilation patterns of HVLS fans are elusive and not well understood. Air driven by the fans moves in many different directions, all of which may affect a fire burning nearby. Fan air speeds are also inconsistent and vary greatly by location and elevation. Review of test data from Phase I, including video media, showed the vertical force created by the fan appeared to have a greater effect than the horizontal force. The vertical force appeared to prohibit the fire from directly traveling to the ceiling, and thus delayed sprinkler operation. The horizontal force altered the fire plume (tilting the plume in a horizontal orientation) but still allowed the heat to reach the ceiling.

The fan manufacturer provided performance data for the vertical air speeds of the MaxAir Whisperfoil XL. Review of the psychometric chart showed the highest air speeds occurred at approximately ½-⅔ of the blade length (from the center of the fan). Given the 12-foot radius of the selected fan, the fastest air speeds would be found 6-8 feet from the center of the fan hub.

Velocity data was gathered as part of this study in an attempt to understand air movement through each array. Velocity data was gathered with and without the storage in place. The velocity data provided by FM Global confirmed that the fastest vertical air speeds were located at ½-⅔ the length of the blade (from the center of the fan). The velocity data provided by Underwriters Laboratories showed that fastest horizontal air speeds occurred at 5 feet from the floor level. Additional research and testing outside the scope of this project is required to better understand this issue.

For the testing, two ignition locations were selected – near the tip of the fan blade and under the fan hub. The former was selected to maximize fan affect based upon fan performance data. The latter was based upon observations of Phase I testing.

The ignition location for the first test at the FM Global Research Campus was under one sprinkler. All other ignition locations for the remaining tests were between four sprinklers. The igniters were located within the longitudinal flue space for all tests completed at Underwriters Laboratories. Igniters were offset approximately 2 feet into the array from the longitudinal flue space for the tests at the FM Global Research Campus. The fan was centered between four sprinklers when sprinkler spacing was 10 feet by

10 feet. In the CMDA sprinkler tests, where spacing was eight feet by ten feet, the fan was offset one foot south of center.

Two standard igniters were used (e.g., two 3-inch by 6-inch long cellulosic bundles soaked in 8 ounces of gasoline wrapped in a polyethylene bag) in all the tests conducted at Underwriters Laboratories. Two half igniters were used (e.g., two 3-inch by 3-inch long cellulosic bundles soaked in 4 ounces of gasoline wrapped in a polyethylene bag) in the tests conducted at the FM Global Research Campus.

K14 ESFR sprinklers protecting both rack storage and palletized storage arrays were tested. The boundary condition used for all the ESFR tests was a 40-foot ceiling, the maximum allowed by current design standards. A storage height of 30 feet was used for three of the four rack storage tests, the tallest possible given the required clearance of 5 feet above and below the fan. One rack storage test was also completed with a storage height of 15 feet to test a high-clearance condition, 25 feet from ceiling to top of storage. The ESFR palletized storage tests used a storage height of 15 feet to simulate conditions found within picking and receiving areas where handling of product was the priority, not maximization of storage density.

The following pass/fail criteria were established for the ESFR sprinkler tests:

1. A maximum of eight sprinklers activate.
2. The fire is generally contained to the ignition array.
3. Ceiling gas temperatures are such that exposed structural steel would not be endangered (peak one minute average temperatures less than 1,000^{o}F).

In Tests 1 and 2 (FM-1 and FM-2), which tested rack storage array to 30 feet, the HVLS fan was at full speed during the entire test. Both these tests were considered failures because the fire burned to the target arrays and an excessive amount of sprinklers operated (12 sprinklers in each test). Test 2 (FM-2), which was considered the worst case and had the fan hub positioned above the ignition location, was repeated with fan shutdown upon waterflow of the first sprinkler plus a 90-second delay. This test, Test 3A (FM-3), was a success with only four sprinklers operating and minimal commodity damage.

Test 3B (FM-4) was a repeat of Test 3A (FM-3); however, a reduced storage height of 15 feet was used. This test was a success with only four sprinklers operating and minimal commodity damage.

Review of the ESFR rack storage testing data showed the most challenging fan to ignition location was with the fan hub centered over ignition. This is consistent with the Phase I FPRF work.

Increasing the clearance from the top of storage to the ceiling from 10 feet in Test 3A (FM-3) to 25 feet in Test 3B (FM-4) had little effect on the number of operating sprinklers, sprinkler activation times, or ceiling temperatures. Additionally, fuel consumption was much less with the larger clearance, 0.5 versus 2.5 equivalent pallets. This was surprising, as it is generally believed that larger clearances delay sprinkler response, resulting in a larger number of sprinklers activating and more commodity damage than with smaller clearances. One possible explanation, which was not further validated, could be that the fan air pattern was distorted by the top of the rack array in Test 3A (FM-3), which was 15 feet closer than in Test 3B (FM-4), resulting in greater disruption of the upward moving fire plume.

In Tests 4 and 5 (UL-1 and UL-2), palletized storage array with a storage height of 15 feet was tested. The HVLS fan operated at full speed the entire duration of both tests. In Test 4 (UL-1), the ignition location was near the fan tip and in Test 5 (UL-2), the ignition was located under the hub. Both were successful, activating six sprinklers with acceptable damage.

The success of the ESFR palletized testing resulted in speculation that fan affect on sprinkler system performance was influenced more by fan characteristics, such as blade number or orientation, than the characteristics of the array. In an effort to explore this theory, XL GAPS conducted a full-scale fire test (Test 9) on November 11, 2010 at the Underwriters Laboratories large scale fire test facility located in Northbrook, Illinois. Test 9 (UL-6), duplicated Test 4 (UL-1) except that a Rite-Hite Revolution 24-foot diameter, 4-blade, 48 RPM HVLS fan was used in lieu of the MaxAir Whisperfoil XL 24-foot diameter, 6-blade, 64 RPM HVLS fan. The Rite-Hite Revolution fan was the same model used in the 2007 XL GAPS Test 1 (CMDA sprinklers) and was operated at 64 RPM the entire duration of the test.

Comparison of the preliminary data from the two tests showed minimal difference; the number of sprinklers which operated increased by two (6 versus 8), sprinkler response was reduced (from 1 minute 21 seconds to 56 seconds), and maximum one minute ceiling temperatures increased slightly (from 102 degrees F to 131 degrees F). The fire did not burn beyond the ignition array and 28 equivalent pallets were consumed versus 25 equivalent pallets in Test 5[1]. This test was considered acceptable based upon the previously established criteria.

Review of the ESFR palletized storage test data showed that the location of the fan relative to the ignition location had little affect on the performance of the ESFR sprinklers based upon a comparison of the number of operating sprinklers, sprinkler activation times, ceiling temperatures, and commodity consumed. ESFR sprinkler performance was acceptable in all palletized tests, which is consistent with previous testing of this array. See Table E-1, *"Results for Tests 1-3B,"* and Table E-2, *"Results for Tests 4, 5, and 9,"* for a summary of the test results.

Three CMDA sprinkler tests were conducted at the Underwriters Laboratories large scale fire test facility located in Northbrook, Illinois. The highest storage and ceiling heights allowed by current design standards, 15 feet and 25 feet respectively, were selected for these tests and palletized storage array was used.

The following pass/fail criteria were established for the CMDA sprinkler tests:

1. A maximum of 20 sprinklers operate (operating area of 1,600-2,000 square feet).
2. Ceiling gas temperatures are such that exposed structural steel would not be endangered (peak one minute average temperatures less than 1,000^{o} F).
3. The fire does not burn to the end of the main test array or jump the aisle and ignite the target arrays.

In Test 6 (UL-3), the HVLS fan was located such that the ignition location was near the fan tip. The fan was operating at full speed until activation of the air sampling-type detector, which occurred at 1 minute and 36 seconds. The fan was then de-energized. Six sprinklers activated and the fire did not spread to the end of the main array or to the target arrays. The test was considered a success.

[1] Preliminary Data Provided at the Courtesy of Pete Willse of XL GAPS.

Test 7 (UL-4) was a repeat of Test 6 (UL-3), only the ignition location was moved to under the fan hub. The fan was shutdown by activation of the first ionization detector at 1 minute and 43 seconds. Seven sprinklers activated and the fire did not spread to the end of the main array or to the target arrays. The test was also considered a success.

Test 8 (UL-5) was a repeat of Test 6 (UL-3), with the fan at full speed until the operation of the first sprinkler. Then after a 90-second delay, the fan was de-energized. Twenty sprinklers activated and the fire did not spread to the end of the main array or to the target arrays. The test was considered a success. See Table E-3, *"Results for Tests 6-8,"* for a summary of the test results.

The drastically different outcome of Tests 6-8 (UL-3-5) in comparison to that of the 2007 XL GAPS Test 1 which operated 73 sprinklers was puzzling. In an attempt to explain the unique results of the latter, an extensive review of numeric data, visual media, and other material from the 2007 XL GAPS Test 1 was completed.

Due to the significant reduction in sprinkler density that occurred during the test, smaller igniter size, and questions regarding other details of the test, the data from 2007 XL GAPS Test 1 was considered unreliable. Therefore, comparison to the results of Tests 6-8 (UL-3-5) was of minimum value.

The following conclusions were drawn from the specific fire tests conducted:

1. K14 ESFR sprinklers can adequately protect cartoned, unexpanded Group A plastic in double row rack storage array to a height of 30 feet beneath a 40-foot ceiling in the presence of HVLS fans when the fans are shutdown no later than 90 seconds after waterflow of the first operating sprinkler.
2. K14 ESFR sprinklers can adequately protect cartoned, unexpanded Group A plastic in palletized storage array to a height of 15 feet beneath a 40-foot ceiling in the presence of HVLS fans operating.
3. K11.2 CMDA sprinklers can adequately protect cartoned, unexpanded Group A plastic in palletized storage array to a height of 15 feet beneath a 25-foot ceiling in the presence of HVLS fans when the fans were shutdown up to 90 seconds after waterflow of the first operating sprinkler.

Table E-1. Results for Tests 1-3B

FIRE TESTS	FPRF Test 1 (FM-1) 8/5/2010	FPRF Test 2 (FM-2) 8/20/2010	FPRF Test 3A (FM-3) 9/2/2010	FPRF Test 3B (FM-4) 12/2/2010
PARAMETERS				
Location of Test	FM Global	FM Global	FM Global	FM Global
Storage Type	Double-Row Rack	Double-Row Rack	Double-Row Rack	Double-Row Rack
Commodity Type	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic
Nominal Storage Height (ft)	30	30	30	15
Nominal Ceiling Height (ft)	40	40	40	40
Nominal Clearance (ft)	10	10	10	25
Aisle Width (in.)	48	48	48	48
Longitudinal/Transverse Flue (in.)	6/6	6/6	6/6	6/6
Ignition Location	Under 1 Sprinklers (offset 2 ft)	Between 4 Sprinklers (offset 2 ft)	Between 4 Sprinklers (offset 2 ft)	Between 4 Sprinklers (offset 2 ft)
Igniter Details	2 Half Igniters – 3" by 3" Each with 4 oz Gasoline	2 Half Igniters – 3" by 3" Each with 4 oz Gasoline	2 Half Igniters – 3" by 3" Each with 4 oz Gasoline	2 Half Igniters – 3" by 3" Each with 4 oz Gasoline
Sprinkler Type/Temperature Rating (°F)	ESFR/165	ESFR/165	ESFR/165	ESFR/165
Sprinkler Orientation	Pendent	Pendent	Pendent	Pendent
Sprinkler Sensitivity	Fast Response	Fast Response	Fast Response	Fast Response
Sprinkler Make/Model Number	Tyco/ESFR-1	Tyco/ESFR-1	Tyco/ESFR-1	Tyco/ESFR-1
Deflector to Ceiling (in.)	14	14	14	14
Nominal Sprinkler Discharge Coefficient K (gpm/psi^{½})	14	14	14	14
Density/Nominal Sprinkler Discharge Pressure (psi)	75	75	75	75
Sprinkler Spacing (ft x ft)	10 x 10	10 x 10	10 x 10	10 x 10
Fan Size (ft)	24	24	24	24
Fan Location	Fan Tip 4.9 ft Beyond Ignition	Hub Above Ignition (no offset)	Hub Above Ignition (no offset)	Hub Above Ignition (no offset)
Fan Distance Below Ceiling (in.)	50	50	50	50
HVLS Fan Speed (rpm)	66	66	66	66
HVLS Fan Operation	On (no shutdown)	On (no shutdown)	Off at Waterflow (90 sec delay)	Off at Waterflow (90 sec delay)
HVLS Fan Manufacturer	MacroAir	MacroAir	MacroAir	MacroAir
HVLS Fan Model Name	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL
HVLS Fan Model Number	MA24XL2006	MA24XL2006	MA24XL2006	MA24XL2006
HVLS Fan Blade Geometry	Whisperfoil XL	Whisperfoil XL	Whisperfoil XL	Whisperfoil XL
HVLS Fan Number of Blades	6	6	6	6
RESULTS				
Length of Test (hr:min:s)	0:35:00	0:25:00	0:30:00	0:30:00
First Ceiling Sprinkler Operation (min:s)	1:28	1:42	1:54	1:39
Last Ceiling Sprinkler Operation (min:s)	7:53	3:57	2:03	1:42
Number of Operated Ceiling Sprinklers	12	12	4	4
Peak Steel Temperature at Ceiling Above Ignition (°F)	169	117	113	113
Max. 1 Min. Average Steel Temperature Above Ignition (°F)	559	266	291	112
Fire Spread Across Aisle	YES	YES	NO	NO
Fire spread to the Ends of the Array	NO	NO	NO	NO
Fuel Consumed (number of pallets)	12.5	5	2.5	0.5
Test Outcome (Pass/Fail)	FAIL	FAIL	PASS	PASS
Comments	Test failed due to 12 sprinklers activating	Test failed due to 12 sprinklers activating	Repeat of Test 2 with fan shutdown at waterflow	Repeat of Test 3A with 15 feet storage height

Table E-2. Results for Tests 4, 5, and 9

FIRE TESTS	FPRF Test 4 (UL-1) 9/15/2010	FPRF Test 5 (UL-2) 9/17/2010	FPRF Test 9 (UL-6) 11/12/2010
PARAMETERS			
Location of Test	U.L.	U.L.	U.L.
Storage Type	Palletized Open Array	Palletized Open Array	Palletized Open Array
Commodity Type	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic
Nominal Storage Height (ft)	15	15	15
Nominal Ceiling Height (ft)	40	40	40
Nominal Clearance (ft)	25	25	25
Aisle Width (in.)	N/A	N/A	N/A
Longitudinal/Transverse Flue (in.)	12	12	12
Ignition Location	Between 4 Sprinklers (centered)	Between 4 Sprinklers (centered)	Between 4 Sprinklers (centered)
Igniter Details	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline
Sprinkler Type/Temperature Rating (°F)	ESFR/165	ESFR/165	ESFR/165
Sprinkler Orientation	Pendent	Pendent	Pendent
Sprinkler Sensitivity	Fast Response	Fast Response	Fast Response
Sprinkler Make/Model Number	Tyco/ESFR-1	Tyco/ESFR-1	Tyco/ESFR-1
Deflector to Ceiling (in.)	14	14	14
Nominal Sprinkler Discharge Coefficient K (gpm/psi^{½})	14	14	14
Density/Nominal Sprinkler Discharge Pressure (psi)	75	75	75
Sprinkler Spacing (ft x ft)	10 x 10	10 x 10	10 x 10
Fan Size (ft)	24	24	24
Fan Location	Fan Tip 2 ft Beyond Ignition	Hub Above Ignition	Fan Tip 2 ft Beyond Ignition
Fan Distance Below Ceiling (in.)	54.5	54.5	72
HVLS Fan Speed (rpm)	63	63	64
HVLS Fan Operation	On (no shutdown)	On (no shutdown)	On (no shutdown)
HVLS Fan Manufacturer	MacroAir	MacroAir	Rite-Hite
HVLS Fan Model Name	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL	Revolution
HVLS Fan Model Number	MA24XL2006	MA24XL2006	-
HVLS Fan Blade Geometry	Whisperfoil XL	Whisperfoil XL	Propell-Aire Standard
HVLS Fan Number of Blades	6	6	4
RESULTS			
Length of Test (hr:min:s)	0:30:00	0:30:00	0:30:00
First Ceiling Sprinkler Operation (min:s)	1:21	1:05	0:56
Last Ceiling Sprinkler Operation (min:s)	1:47	1:57	1:51
Number of Operated Ceiling Sprinklers	6	6	8
Peak Gas Temperature at Ceiling Above Ignition (°F)	207	181	181
Max. 1 Min. Average Gas Temp. at Ceiling Above Ignition (°F)	131	154	131
Peak Steel Temperature at Ceiling Above Ignition (°F)	102	118	121
Max. 1 Min. Average Steel Temp. Above Ignition (°F)	100	105	116
Fire Spread Across Aisle	NO	NO	NO
Fire spread to the Ends of the Array	NO	NO	NO
Fuel Consumed (number of pallets)	25	23	28
Test Outcome (Pass/Fail)	PASS	PASS	PASS
Comments			Repeat of Test 4 using different fan model

Table E-3. Results for Tests 6-8

FIRE TESTS	FPRF Test 6 (UL-3) 9/21/2010	FPRF Test 7 (UL-4) 9/23/2010	FPRF Test 8 (UL-5) 9/28/2010
PARAMETERS			
Location of Test	U.L.	U.L.	U.L.
Storage Type	Palletized Open Array	Palletized Open Array	Palletized Open Array
Commodity Type	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic
Nominal Storage Height (ft)	15	15	15
Nominal Ceiling Height (ft)	25	25	25
Nominal Clearance (ft)	10	10	10
Aisle Width (in.)	N/A	N/A	N/A
Longitudinal/Transverse Flue (in.)	12	12	12
Ignition Location	Between 4 Sprinklers (centered)	Between 4 Sprinklers (centered)	Between 4 Sprinklers (centered)
Igniter Details	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline
Sprinkler Type/Temperature Rating (°F)	CMDA/286	CMDA/286	CMDA/286
Sprinkler Orientation	Upright	Upright	Upright
Sprinkler Sensitivity	Std. Response	Std. Response	Std. Response
Sprinkler Make/Model Number	Tyco/ELO-231-B	Tyco/ELO-231-B	Tyco/ELO-231-B
Deflector to Ceiling (in.)	3	3	3
Nominal Sprinkler Discharge Coefficient K (gpm/psi½)	11.2	11.2	11.2
Density/Nominal Sprinkler Discharge Pressure (psi)	0.60 gpm/sq ft	0.60 gpm/sq ft	0.60 gpm/sq ft
Sprinkler Spacing (ft x ft)	8 x 10	8 x 10	8 x 10
Fan Size (ft)	24	24	24
Fan Location	Fan Tip 3 ft Beyond Ignition	Hub 1 ft West of Ignition	Fan Tip 3 ft Beyond Ignition
Fan Distance Below Ceiling (in.)	54.5	54.5	54.5
HVLS Fan Speed (rpm)	63	63	63
HVLS Fan Operation	Off at Air Sampling-Type Detection (1:36) (no delay)	Off at Ion Smoke Detector Operation (1:43) (no delay)	Off at Waterflow (90 sec delay)
HVLS Fan Manufacturer	MacroAir	MacroAir	MacroAir
HVLS Fan Model Name	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL
HVLS Fan Model Number	MA24XL2006	MA24XL2006	MA24XL2006
HVLS Fan Blade Geometry	Whisperfoil XL	Whisperfoil XL	Whisperfoil XL
HVLS Fan Number of Blades	6	6	6
RESULTS			
Length of Test (hr:min:s)	0:30:00	0:30:00	0:30:00
First Ceiling Sprinkler Operation (min:s)	1:36	2:08	1:13
Last Ceiling Sprinkler Operation (min:s)	1:58	3:28	3:01
Number of Operated Ceiling Sprinklers	6	7	20
Peak Gas Temperature at Ceiling Above Ignition (°F)	1468	504	1506
Max. 1 Min. Average Gas Temp. at Ceiling Above Ignition (°F)	1042	360	1287
Peak Steel Temperature at Ceiling Above Ignition (°F)	244	122	415
Max. 1 Min. Average Steel Temp. Above Ignition (°F)	219	122	410
Fire Spread Across Aisle	NO	NO	NO
Fire spread to the Ends of the Array	NO	NO	NO
Fuel Consumed (number of pallets)	26	15	32
Test Outcome (Pass/Fail)	PASS	PASS	PASS
Comments		Fan blades failed (bent) after shutdown	

INTRODUCTION

High Volume/Low Speed (HVLS) fans are routinely used in industrial buildings protected with automatic sprinkler systems. The large physical size and capacity of these fans created concerns among the fire protection community regarding their impact on sprinkler performance. These concerns provided the impetus for the Fire Protection Research Foundation (FPRF) to commission the research project "*HVLS Fan and Sprinkler Operation*" in 2008.

Phase I of this study, completed by Aon Fire Protection Engineering (formerly Schirmer Engineering), focused on the degree of sprinkler water spray obstruction that fans create, as well as the impact of fan-induced airflow on the rate of fire spread through commodity arrangements.

This initial phase of the research program included laboratory testing intended to measure the degree of sprinkler obstruction caused by HVLS fans through a series of Actual Delivery Density (ADD) tests. Additionally, two full-scale tests were conducted to measure fan airflow effects on sprinkler performance. Due to budget constraints, the focus of Phase I was limited to Early Suppression Fast Response (ESFR) sprinkler technology with standard plastic test commodity in rack storage array.

Information obtained from Phase I work provided a foundation for the second phase of this study. Phase II focused on full-scale fire testing to examine the effect of HVLS fans on both ESFR and Control Mode Density Area (CMDA) sprinkler performance. Cartoned, unexpanded Group A plastic was used for all testing. The goals of Phase II of the project were as follows:

1. Complete the initial focus of Phase I to analyze the impact of HVLS fans on ceiling ESFR sprinkler performance for rack storage arrays.
2. Expand the investigation to include HVLS fan affect on ESFR sprinkler performance for palletized storage arrays.
3. Analyze HVLS fan affect on CMDA sprinkler performance for both rack storage and palletized storage arrays.
4. If possible, collect measurements of the airflow created by the HVLS fans within the flue spaces of each array.

LITERATURE REVIEW

A review of existing data regarding the testing of HVLS fans and sprinklers was conducted. This review was undertaken to ensure new information released since completion of Phase I of the project would be considered. Data from ten full-scale fire tests, including the two conducted by the FPRF in Phase I of the project, was accumulated for review (see Appendix A – Summary of Previous HVLS Fan Testing).

Unfortunately, this testing was completed by three different groups, mostly operating independent of each other. Although there was a significant amount of data, drawing conclusions based upon scientific principles was challenging. Nonetheless, the following conclusions were made:

1. K14 ESFR sprinklers provided acceptable protection of cartoned, unexpanded Group A plastic, 20 feet high under a 30-foot ceiling in double-row rack storage array with HVLS fans operating at full speed. ESFR sprinklers also provided acceptable protection of the same commodity in palletized storage array (15 feet high under a 26-foot ceiling) when the HVLS fan was shutdown upon waterflow of the first operating sprinkler or activation of the air sampling-type detector.
2. K11.2 CMDA sprinklers provided acceptable protection of the cartoned, unexpanded Group A plastic in rack storage array (15 feet high under a 25-foot ceiling) when the HVLS fan was shutdown upon waterflow of the first operating sprinkler.

EXPERIMENTAL TEST PLAN

The primary goal of Phase II was to investigate the effect HVLS fans have on the performance of both ESFR and CMDA sprinklers. Full-scale fire testing, although expensive, was selected as the most accurate method to achieve this goal. A maximum of ten full-scale fire tests were planned; seven using ESFR sprinklers and three using CMDA sprinklers. The test scenarios were specifically selected to explore the impact of relevant variables in a systematic manner.

The fan selected for all tests was the MaxAir Whisperfoil XL (Model MA24XL2006) manufactured by MacroAir. This fan had six blades and was 24 feet in diameter. Performance data provided by MacroAir indicated the fan produced approximately 330,000 cfm at 63 rpm.

The performance characteristics of HVLS fans are elusive and not well understood. Air driven by the fans moves in many different directions, all of which may affect a fire burning nearby. Fan air speeds are also inconsistent and vary greatly by location and elevation. Review of test data from Phase I, including video media, showed the vertical force created by the fan appeared to have a greater effect than the horizontal force. The vertical force appeared to prohibit the fire from directly rising to the ceiling, and thus delayed sprinkler operation. The horizontal force altered the fire plume (tilting the plume in a horizontal orientation) but still allowed the heat to reach the ceiling.

Performance data for the vertical air speeds of the selected fan was provided by the fan manufacturer. Review of the psychometric chart for the MaxAir Whisperfoil XL showed the highest air speeds occurred at approximately ½-⅔ of the blade length from the center of the fan. Given the 12-foot radius of the selected fan, the fastest air speeds would be found 6-8 feet from the center of the fan hub. Ignition locations were selected to maximize this affect.

ESFR Sprinkler Rack Storage Testing

Previous testing of ESFR sprinklers and HVLS fans was successful for rack storage array of cartoned, unexpanded Group A plastic, 20 feet high under a 30-foot ceiling. In Phase II, new tests were designed to challenge the ESFR sprinklers to their limit by maximizing storage/ceiling height. The highest ceiling allowed (40 feet) in National Fire Protection Association *"Standard for the Installation of Sprinkler Systems,"* 2010 Edition (NFPA 13) and FM Global Property Loss Prevention Data Sheet *"Storage of Class 1, 2, 3, 4, and Plastic Commodities,"* 2010 Edition (FM Global DS 8-9) for ceiling-only K14 ESFR sprinklers was selected. The storage height was determined by subtracting the required fan clearances from the ceiling height.

Review of design guidelines from fan manufacturers indicated a clearance of approximately 3.5-5 feet was required between the fan and the ceiling above, and the same from the fan to the rack below, assuming a fan diameter of 24 feet. Thus, the minimum space needed was approximately 7-10 feet. A ceiling to storage clearance of 10 feet was selected (as in Phase I), resulting in a storage height of 30 feet. Compliance with this clearance was also consistent with the concept of treating the fans as sprinkler obstructions, which are governed by the requirements of NFPA 13 or FM Global Property Loss Prevention Data Sheet *"Installation Guidelines for Automatic Sprinklers,"* 2010 Edition (FM Global DS 2-0). Both documents require a minimum clearance of 3 feet from the fan to the ESFR sprinkler above and from the fan to the storage below.

Also, to test the effect of excess clearance from the ceiling to the top of storage, one test was planned using 15 feet of storage beneath a 40-foot ceiling.

Two ignition locations were selected – near the tip of the fan blade and under the fan hub. The former was selected based upon fan performance data, the latter based upon observations of Phase I testing. The ignition locations of under one sprinkler and centered between four sprinklers (both offset from the longitudinal flue) were selected. An ignition location between two sprinklers was not possible due to pipe interference issues at the FM Global Research Campus. The fan was centered between four sprinklers in all ESFR sprinkler tests. Figure 1 shows proposed test configurations.

Failure of either test would result in a repeat of the failed test, or the worst-case test, should both fail. Additionally, the protocol for any repeated test would be to require the fan to be automatically de-energized upon waterflow. A 90-second delay in the shutdown of the fan upon waterflow would be used to simulate the delay allowed by NFPA 72, *The National Fire Alarm Code.*

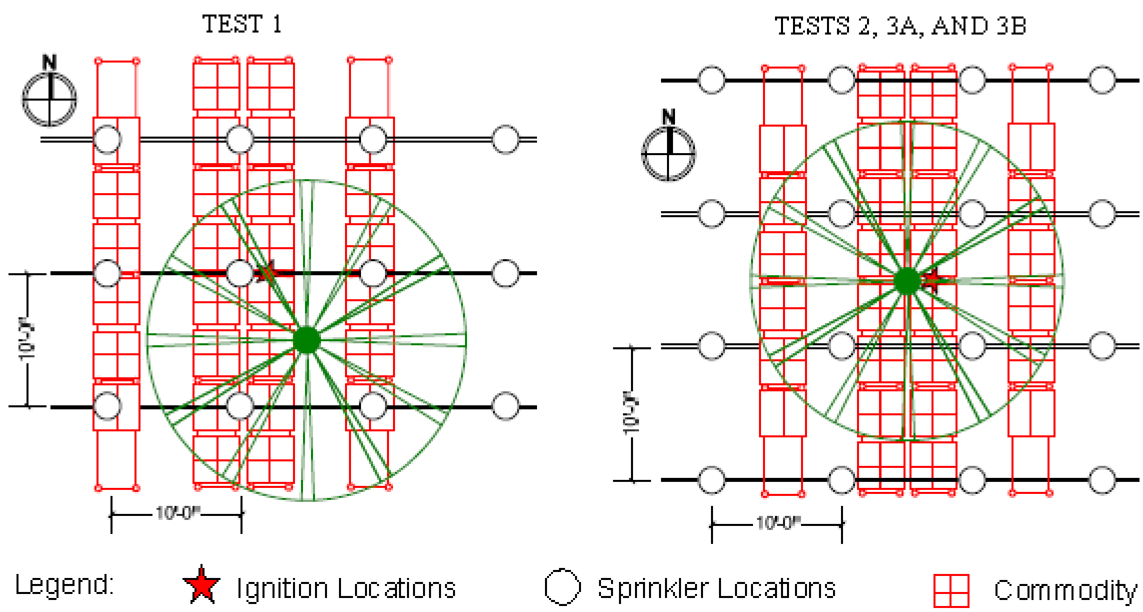


Figure 1. Orientation of Fan, Ignition Location, and Sprinklers for Tests 1-3B (Courtesy of FM Global)

ESFR Sprinkler Palletized Storage Testing

Field survey data of 46 warehouse locations complied by Zurich indicated that 80% of HVLS fan installations were located over areas normally occupied by people, such as loading docks or sorting/picking areas (55% and 25% respectively). Data from Travelers was similar. This data is consistent with the concept that HVLS fans are primarily used for worker comfort within these facilities.

Storage on loading docks or in sorting/picking areas is generally lower than in storage areas to facilitate human handling and loading of material into transportation vehicles. Maximization of storage capacity is not an objective in these areas. Zurich data confirmed the maximum height of storage within loading docks or sorting/picking areas was 15 feet, versus 42 feet in storage areas. Also, it was found that most loading docks or sorting/picking areas did not have low ceilings; building height in these areas was the same as within the building's storage area.

The test configuration selected was based upon these survey findings. A ceiling height of 40 feet (tallest allowed by both NFPA 13 and FM Global DS 8-9 for K14 ESFR sprinkler protection) was used, under which open array palletized storage to 15 feet was located. Two tests were planned.

Because no testing of palletized storage arrays protected by ESFR sprinklers could be found, the array configuration was based upon FM Global Approval Standard 2000 and UL Standard UL-199 for the approval of CMDA K11.2 sprinklers. Figure 2 shows proposed test configurations.

Failure of either test would result in a repeat of the failed test, or the worst-case test should both fail. Additionally, the protocol for any repeated test would be to require the fan to be automatically de-energized upon waterflow. A 90-second delay in the shutdown of fan upon waterflow would be used to simulate the delay allowed by NFPA 72, *The National Fire Alarm Code.*

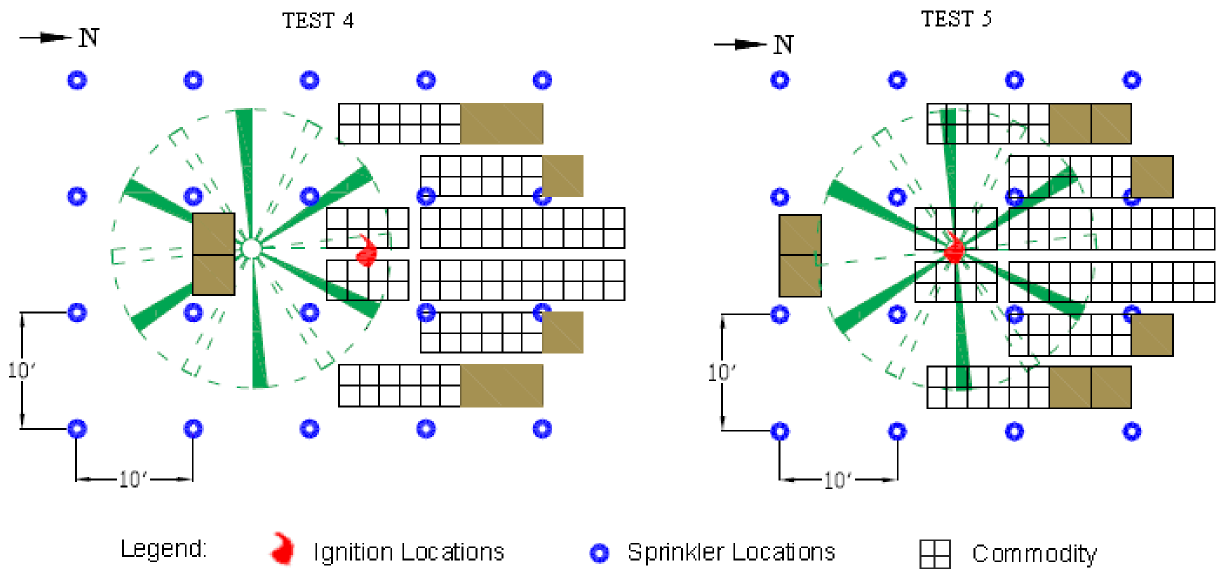


Figure 2. Orientation of Fan, Ignition Location, and Sprinklers for Tests 4-5 (Courtesy of UL)

Pass/Fail Criteria for All ESFR Tests

The development of pass/fail criteria for K14 ESFR sprinklers was challenging, especially for the storage configurations planned. First developed in the 1980s as the original ESFR sprinkler, the legacy of the K14 ESFR sprinkler's performance is exceptional. So much so that present day approval standards of both FM Global and Underwriters Laboratories do not require full-scale fire testing of pendent K14 ESFR sprinklers, only evaluation of other performance criteria such as water distribution and sensitivity. Other ESFR sprinklers, such as those with K-factors of 16.8-25, require full-scale fire testing as part of the approval process. Additionally, none of the past K14 ESFR tests included palletized storage array.

The following pass/fail criteria were established:

1. A maximum of eight sprinklers activate - This is the same criterion established for K22.4 ESFR sprinklers for similar ceiling/storage heights[2]. The initial ESFR sprinkler study included pass/fail criteria of not more than four sprinklers activating, when the sprinklers operated in the proper sequence. Discussions with FM Global research staff, as well as others involved in the development of the ESFR sprinkler, leads one to believe this criterion is not consistent with the current knowledge base of ESFR performance. Furthermore, the baseline testing series defined tests with 10 sprinklers activating as acceptable[3].
2. The fire is generally contained to the ignition array - The ignition array is defined as the center stacks, two pallet-loads long by two pallet-loads wide, of the main fuel array in which the igniters are located[4]. Figure 3 shows the location of a typical ignition array.
3. Ceiling gas temperatures are such that exposed structural steel would not be endangered (peak one minute average temperatures less than 1,000°F) - This is consistent with all current ESFR sprinkler test criteria.

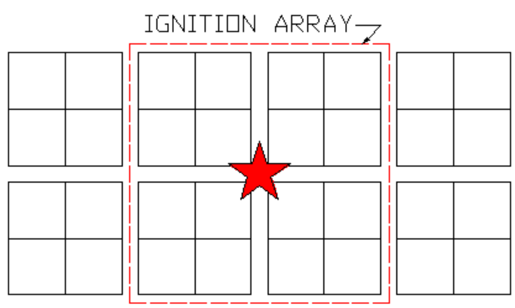


Figure 3. Typical Ignition Array

CMDA SPRINKLER PALLETIZED STORAGE TESTING

The highest storage and ceiling heights allowed in NFPA 13 and FM Global DS 8-9 for ceiling only K11.2 CMDA sprinklers, 15 feet and 25 feet respectively, were selected for these tests. Array configuration and ignition location were in accordance with FM Global Approval Standard 2000 and UL Standard UL-199 for the approval of CMDA K11.2 sprinklers. These parameters also duplicated the 2007 XL GAPS Test 1 which opened 73 sprinklers, despite fan shutoff at sprinkler waterflow. An earlier method of fan shutdown was planned in an attempt to improve the sprinkler performance. An air sampling-type detector and standard ionization spot detectors were selected for this task.

2 FM Global Approved Standard for Suppression Mode Automatic Sprinklers, Class Series 2008, October 2006.

3 National Quick Response Sprinkler Research Project: Large scale Fire Test Evaluation of Early Suppression Fast Response (ESFR) Automatic Sprinklers – National Fire Protection Research Foundation May 1986.

4 HC Kung, Performance Tests for the Central Sprinkler Company Ultra K-25 Fast Response Suppression Sprinkler under 30 Feet and 45 Feet Ceilings, 1997 Factory Mutual Research Corporation.

The air sampling-type detector sampling tube was mounted 18 inches above the fan motor. The sampling tube was spilt so that two inlets were provided. The factory preset sensitivity was as follows:

Alert - 0.08%/ft
Action - 0.14%/ft
Fire 1 - 0.20%/ft
Fire 2 - 2.0%/ft

Five Kidde Model i9070 ionization smoke detectors were installed at the ceiling, with one above the fan and the remaining four spaced at 30 feet on center around the fan. The reported sensitivity of the Kidde detectors was 0.59-1.46%/ft.

Two tests of this configuration were planned. One with the ignition located near the tip of the fan, and another with the ignition located under the fan hub. Figure 4 shows proposed test configurations.

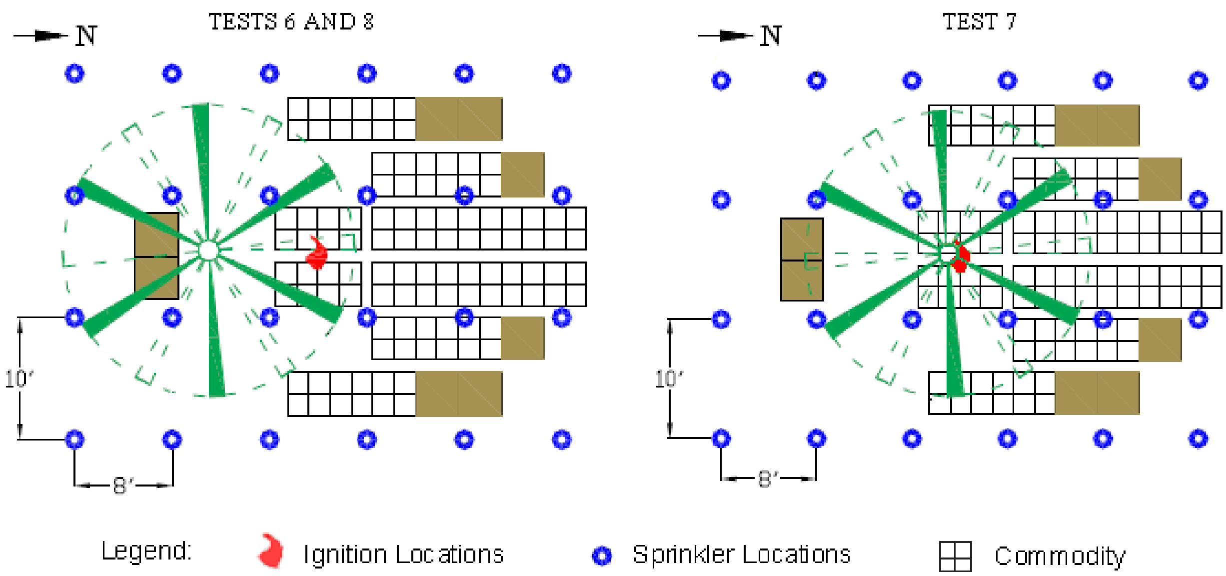


Figure 4. Orientation of Fan, Ignition Location, and Sprinklers for Tests 6-8 (Courtesy of UL)

CMDA Sprinkler Rack Storage Testing

If allowed by the project budget, the final planned test of the series was to be the duplication of the successful XL GAPS 2009 Test, rack storage array to 15 feet, under a 25-foot ceiling, although the fan would be operating at full speed in lieu of being shutdown at sprinkler operation. Storage height, array configuration, and ignition location were in accordance with FM Global Approval Standard 2000 and UL Standard UL-199 for the approval of CMDA K11.2 sprinklers. Figure 5 shows proposed test configuration.

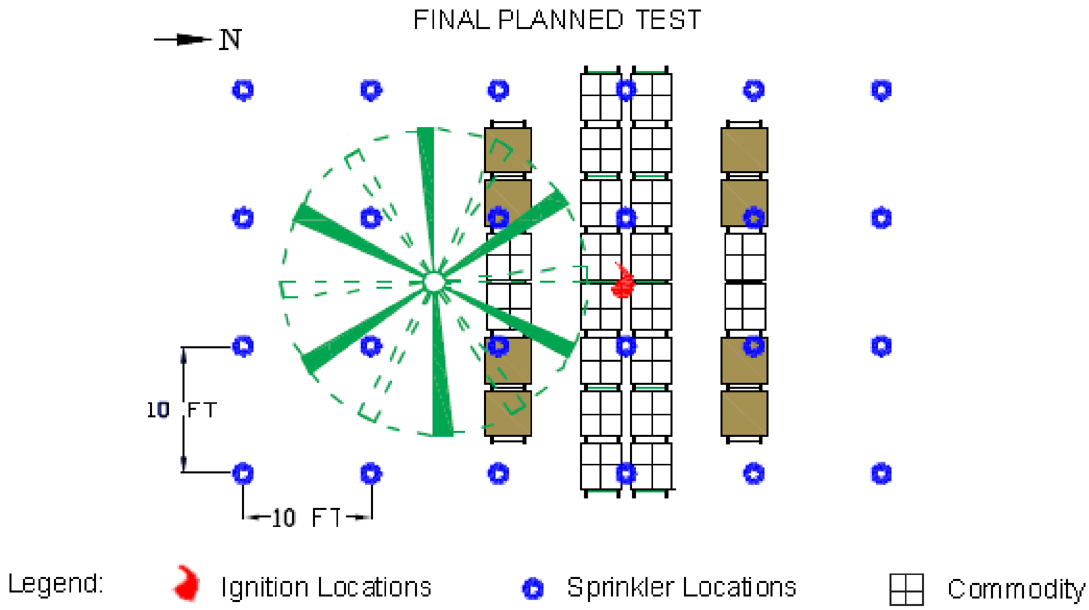


Figure 5. Orientation of Fan, Ignition Location, and Sprinklers for the Final Planned Test (Courtesy of UL)

Pass/Fail Criteria for CMDA Tests

Pass/fail criteria for CMDA sprinkler testing was selected from the appropriate sprinkler approval standards as follows[5,6]:

1. A maximum of 20 sprinklers operate (operating area of 1,600-2,000 square feet).
2. Ceiling gas temperatures are such that exposed structural steel would not be endangered (peak one minute average temperatures less than 1,000° F).
3. The fire does not burn to the end of the main test array or jump the aisle and ignite the target arrays.

EXPERIMENTAL RESULTS AND ANALYSIS

The following sections contain the experimental results and analysis from Phase II for ESFR sprinkler testing, CMDA sprinkler testing, and velocity measurements. Refer to Appendices B (FPRF HVLS Fan Phase II Test Results Summary 1/14/11), C (FM Global Report Excerpts), D (Underwriters Laboratories Fire Test Report), and E (11/12/2010 XL GAPS Test Report Excerpts (Test 9)) for additional details.

[5] FM Global Approval Standard Class Number 2000, Approval Standard for Automatic Control Mode Sprinklers for Fire Protection, March 2006.

[6] Underwriters Laboratory Standard UL-199, Automatic Sprinklers for Fire Protection Service, November 4, 2005.

ESFR Sprinkler Testing

The first four of the seven ESFR sprinkler fire tests were conducted in the Large Burn Lab of the Fire Laboratory at the FM Global Research Campus located in West Glocester, Rhode Island.

In Test 1 (FM-1), 12 sprinklers activated; the first occurring at 1 minute and 28 seconds, the last at 7 minutes and 53 seconds. The fire burned beyond the ignition array and jumped both aisles resulting in extensive damage to the face of both the east and west target arrays. Damage was calculated as 12.5 equivalent pallets. The peak one minute average ceiling temperature was 559 degrees F, which is below the critical value of 1,000 degrees F.

Ceiling temperature data showed that once the maximum temperature was reached, the first ESFR sprinkler activated. The fire was then knocked down temporarily after which a re-growth phase began. Activation of the remaining sprinklers was not adequate to suppress the fire. The result was more representative of fire control, as the heat-release rate of the fire declined gradually after the last sprinkler activated. This test was considered a failure as an excessive number of sprinklers operated and the fire burned to the target arrays.

Test 2 (FM-2) was a repeat of the first test, with the exception that the ignition location was moved to under the fan hub. The number of sprinklers which operated was the same as Test 1 (FM-1), with the first activating at 1 minute and 42 seconds and the last at 3 minutes and 34 seconds. The fire spread within the main array was minimal, and was confined to the ignition bay only. However, the fire quickly jumped the east aisle at 2 minutes and 13 seconds, and traveled to the backside of the east target array. The peak one minute average ceiling temperature was 266 degrees F, which is below the critical value of 1,000 degrees F. This test was considered a failure because the fire jumped the aisle and burned through the target array. Also, an excessive number of sprinklers were activated.

Review of the ESFR rack storage testing data showed that the most challenging fan to ignition location was with the fan hub centered over ignition. This is consistent with the Phase I FPRF work.

Test 3A (FM-3) was a repeat of the most challenging of the two fire tests, Test 2 (FM-2), with the fan at full speed until the operation of the first sprinkler. Then, after a 90 second delay, the fan was automatically de-energized. Four sprinklers operated, with the first activating at 1 minute and 54 seconds and the last at 2 minutes and 3 seconds. The fire spread within the main array was minimal, and was confined to the ignition bay only. The face of the east target sustained minor damage. The peak one minute average ceiling temperature was 113 degrees F, which is below the critical value of 1,000 degrees F. Damage was calculated as 2.5 equivalent pallets. Review of the data showed that ceiling temperatures were slow to climb until approximately one minute (due to downward fan force on the fire) but then correlate well with a standard ESFR fire test. After maximum ceiling temperatures were reached, the four first ring sprinklers activated within nine seconds of each other, and due to the large amount of high momentum water discharged, the fire was extinguished. The results of this test demonstrated the shutdown of the HVLS fan in the early stages of the fire allowed the ESFR sprinklers to function virtually as if no fan was present. This test was considered acceptable based upon the previously established pass/fail criteria.

Test 3B (FM-4) was a repeat of Test 3A (FM-3); however, a reduced storage height of 15 feet was used. This resulted in a clearance of 25 feet between the top of storage and the ceiling. Four sprinklers operated, with the first activating at 1 minute and 39 seconds and the last at 1 minute and 42 seconds. The fire spread within the main array was minimal and was confined to the ignition bay only. The target arrays were not damaged. The peak one minute average ceiling temperature was 113 degrees F, which is below the critical value of 1,000 degrees F. Damage was calculated as 0.5 equivalent pallets. This test was considered acceptable based upon the previously established pass/fail criteria.

Interestingly, increasing the clearance from the top of storage to the ceiling from 10 feet in Test 3A (FM-3) to 25 feet in Test 3B (FM-4) had little affect on the number of operating sprinklers, sprinkler activation times, or ceiling temperatures. Additionally, fuel consumption was much less with the larger clearance, 0.5 versus 2.5 equivalent pallets. This was surprising, as it is generally believed that larger clearances delay sprinkler response, resulting in a larger number of sprinklers activating and more commodity damage than with smaller clearances. One possible explanation, which was not further validated, is that the fan air pattern was distorted by the top of the rack array in Test 3A (FM-3), which was 15 feet closer than in Test 3B (FM-4), resulting in greater disruption of the upward moving fire plume.

A summary of the ESFR sprinkler rack storage tests, along with sprinkler activation diagrams, damage diagrams, and steel temperature diagrams are shown in the following table and figures.

Table 1. Results for Tests 1-3B

FIRE TESTS	FPRF Test 1 (FM-1) 8/5/2010	FPRF Test 2 (FM-2) 8/20/2010	FPRF Test 3A (FM-3) 9/2/2010	FPRF Test 3B (FM-4) 12/2/2010
PARAMETERS				
Location of Test	FM Global	FM Global	FM Global	FM Global
Storage Type	Double-Row Rack	Double-Row Rack	Double-Row Rack	Double-Row Rack
Commodity Type	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic
Nominal Storage Height (ft)	30	30	30	15
Nominal Ceiling Height (ft)	40	40	40	40
Nominal Clearance (ft)	10	10	10	25
Aisle Width (in.)	48	48	48	48
Longitudinal/Transverse Flue (in.)	6/6	6/6	6/6	6/6
Ignition Location	Under 1 Sprinklers (offset 2 ft)	Between 4 Sprinklers (offset 2 ft)	Between 4 Sprinklers (offset 2 ft)	Between 4 Sprinklers (offset 2 ft)
Igniter Details	2 Half Igniters – 3" by 3" Each with 4 oz Gasoline	2 Half Igniters – 3" by 3" Each with 4 oz Gasoline	2 Half Igniters – 3" by 3" Each with 4 oz Gasoline	2 Half Igniters – 3" by 3" Each with 4 oz Gasoline
Sprinkler Type/Temperature Rating (°F)	ESFR/165	ESFR/165	ESFR/165	ESFR/165
Sprinkler Orientation	Pendent	Pendent	Pendent	Pendent
Sprinkler Sensitivity	Fast Response	Fast Response	Fast Response	Fast Response
Sprinkler Make/Model Number	Tyco/ESFR-1	Tyco/ESFR-1	Tyco/ESFR-1	Tyco/ESFR-1
Deflector to Ceiling (in.)	14	14	14	14
Nominal Sprinkler Discharge Coefficient K (gpm/psi½)	14	14	14	14
Density/Nominal Sprinkler Discharge Pressure (psi)	75	75	75	75
Sprinkler Spacing (ft x ft)	10 x 10	10 x 10	10 x 10	10 x 10
Fan Size (ft)	24	24	24	24
Fan Location	Fan Tip 4.9 ft Beyond Ignition	Hub Above Ignition (no offset)	Hub Above Ignition (no offset)	Hub Above Ignition (no offset)
Fan Distance Below Ceiling (in.)	50	50	50	50
HVLS Fan Speed (rpm)	66	66	66	66
HVLS Fan Operation	On (no shutdown)	On (no shutdown)	Off at Waterflow (90 sec delay)	Off at Waterflow (90 sec delay)
HVLS Fan Manufacturer	MacroAir	MacroAir	MacroAir	MacroAir
HVLS Fan Model Name	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL
HVLS Fan Model Number	MA24XL2006	MA24XL2006	MA24XL2006	MA24XL2006
HVLS Fan Blade Geometry	Whisperfoil XL	Whisperfoil XL	Whisperfoil XL	Whisperfoil XL
HVLS Fan Number of Blades	6	6	6	6
RESULTS				
Length of Test (hr:min:s)	0:35:00	0:25:00	0:30:00	0:30:00
First Ceiling Sprinkler Operation (min:s)	1:28	1:42	1:54	1:39
Last Ceiling Sprinkler Operation (min:s)	7:53	3:57	2:03	1:42
Number of Operated Ceiling Sprinklers	12	12	4	4
Peak Steel Temperature at Ceiling Above Ignition (°F)	169	117	113	113
Max. 1 Min. Average Steel Temperature Above Ignition (°F)	559	266	291	112
Fire Spread Across Aisle	YES	YES	NO	NO
Fire spread to the Ends of the Array	NO	NO	NO	NO
Fuel Consumed (number of pallets)	12.5	5	2.5	0.5
Test Outcome (Pass/Fail)	FAIL	FAIL	PASS	PASS
Comments	Test failed due to 12 sprinklers activating	Test failed due to 12 sprinklers activating	Repeat of Test 2 with fan shutdown at waterflow	Repeat of Test 3A with 15 feet storage height

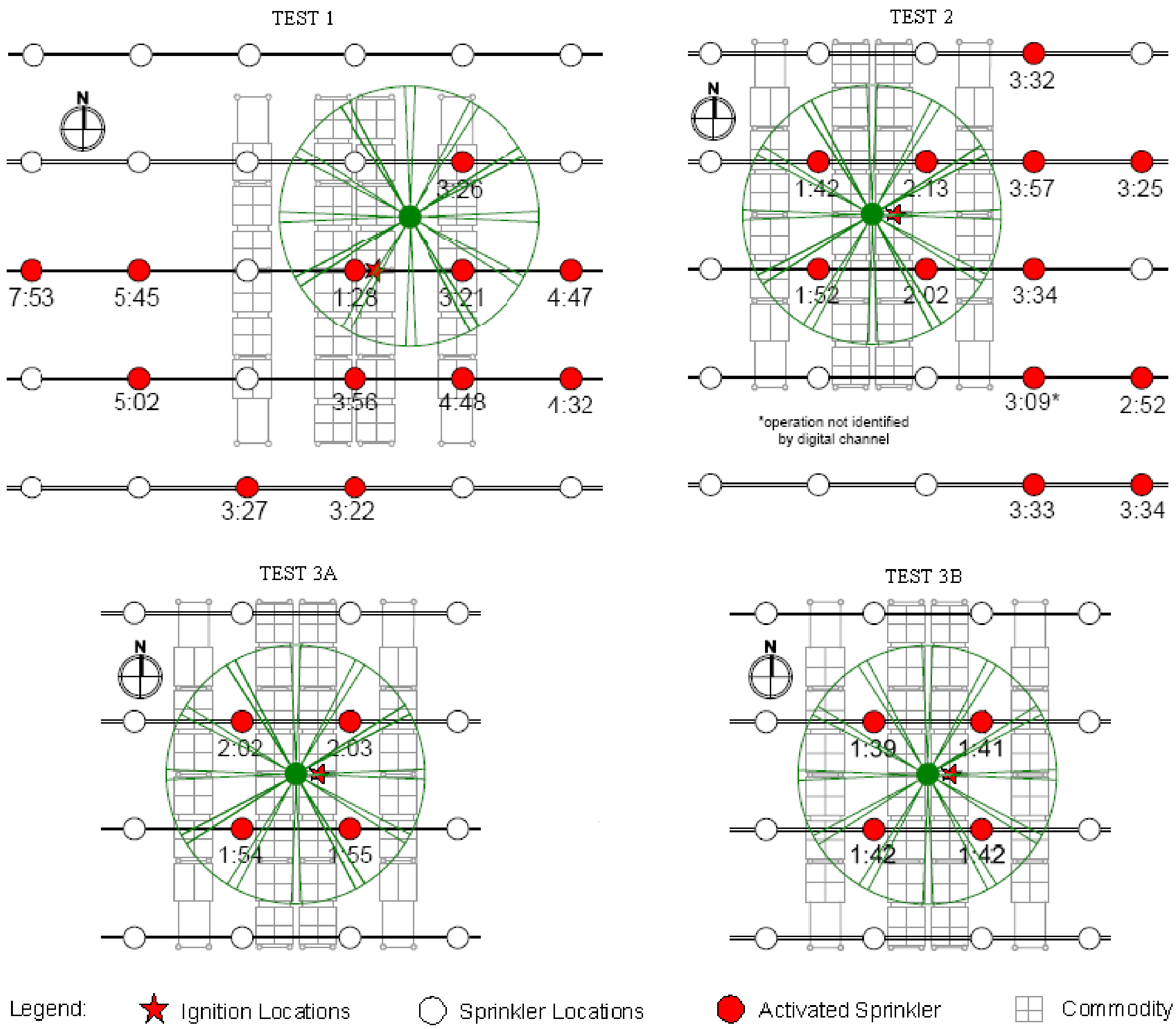
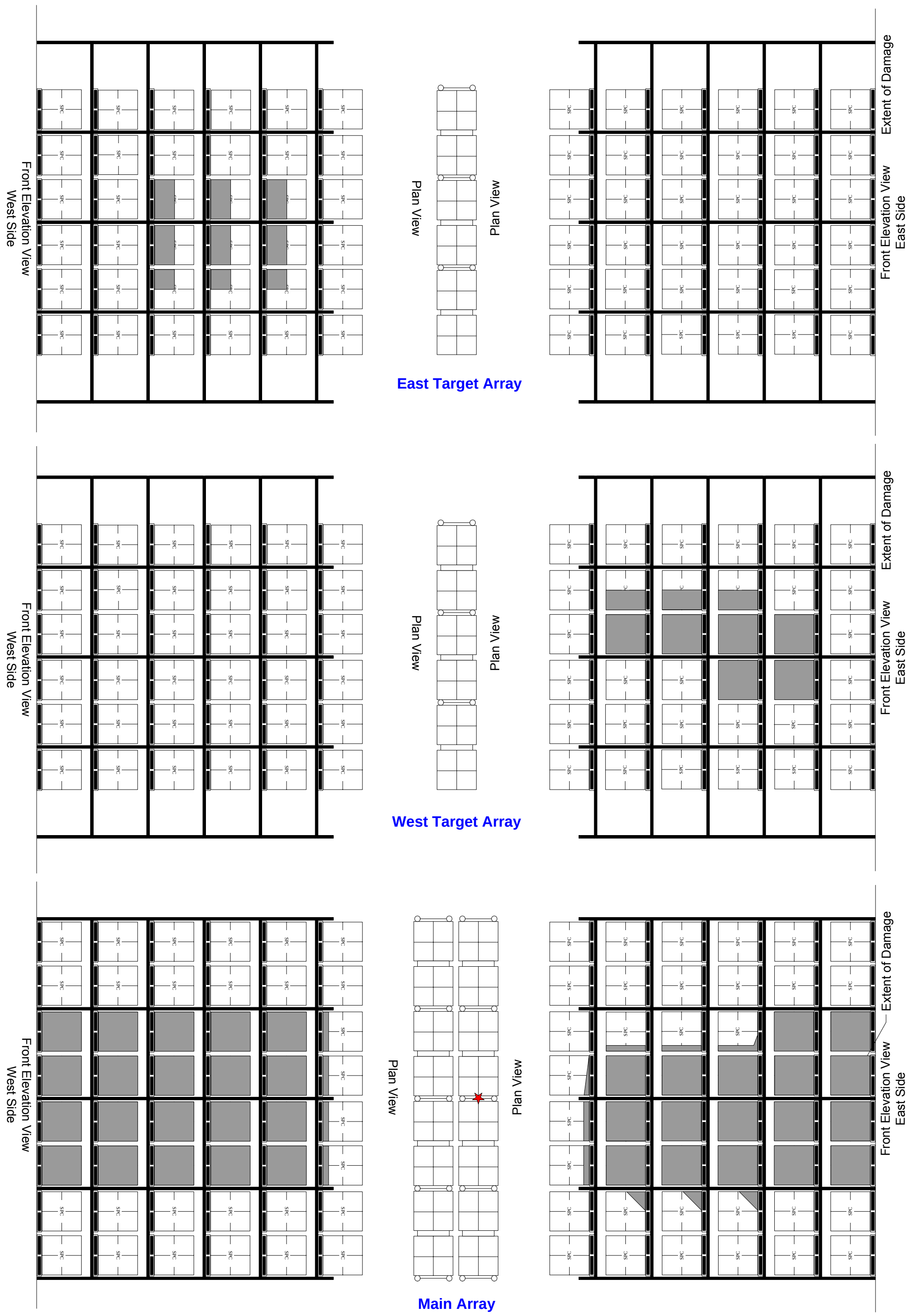
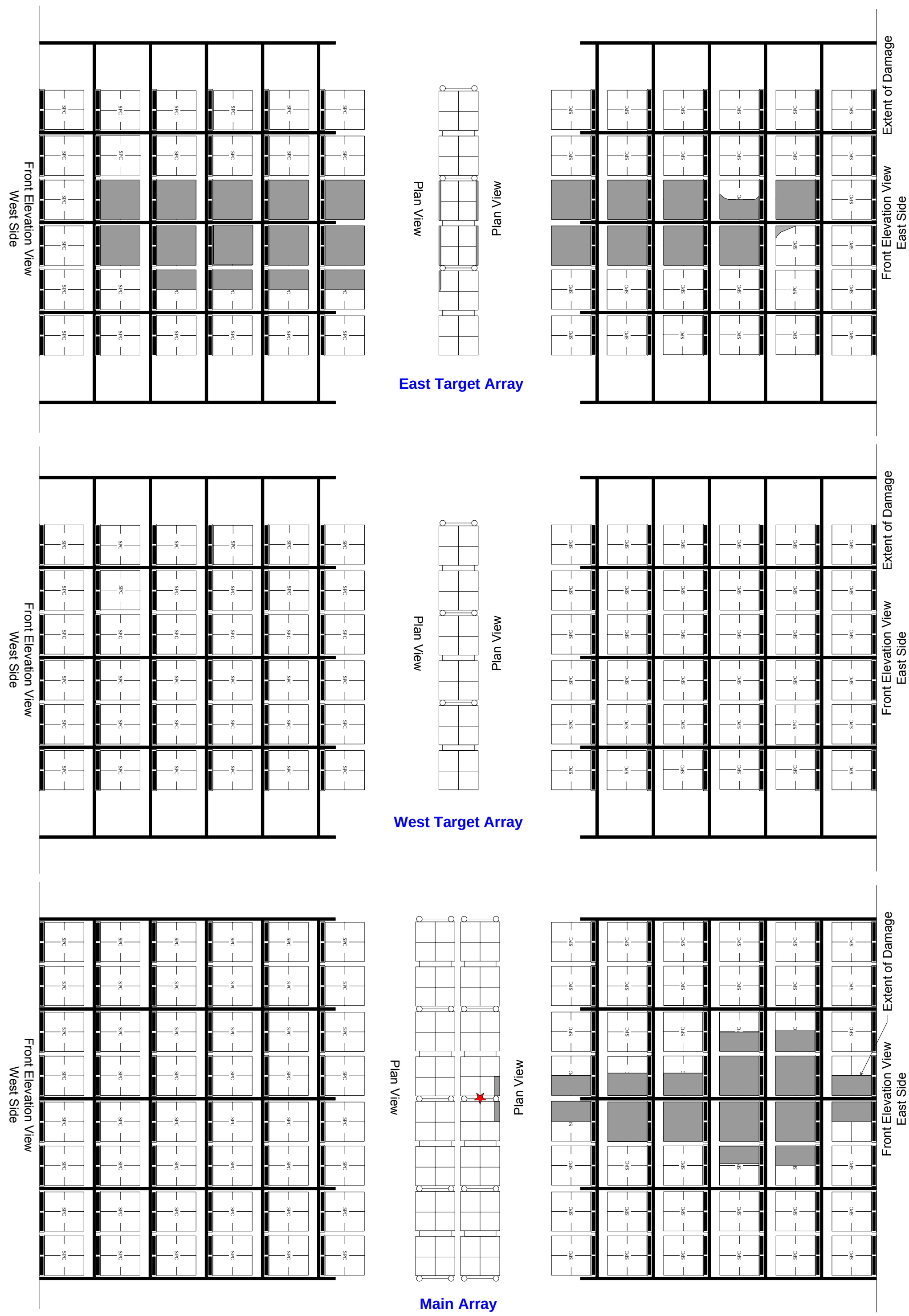


Figure 6. Tests 1-3B Sprinkler Operation (Courtesy of FM Global)



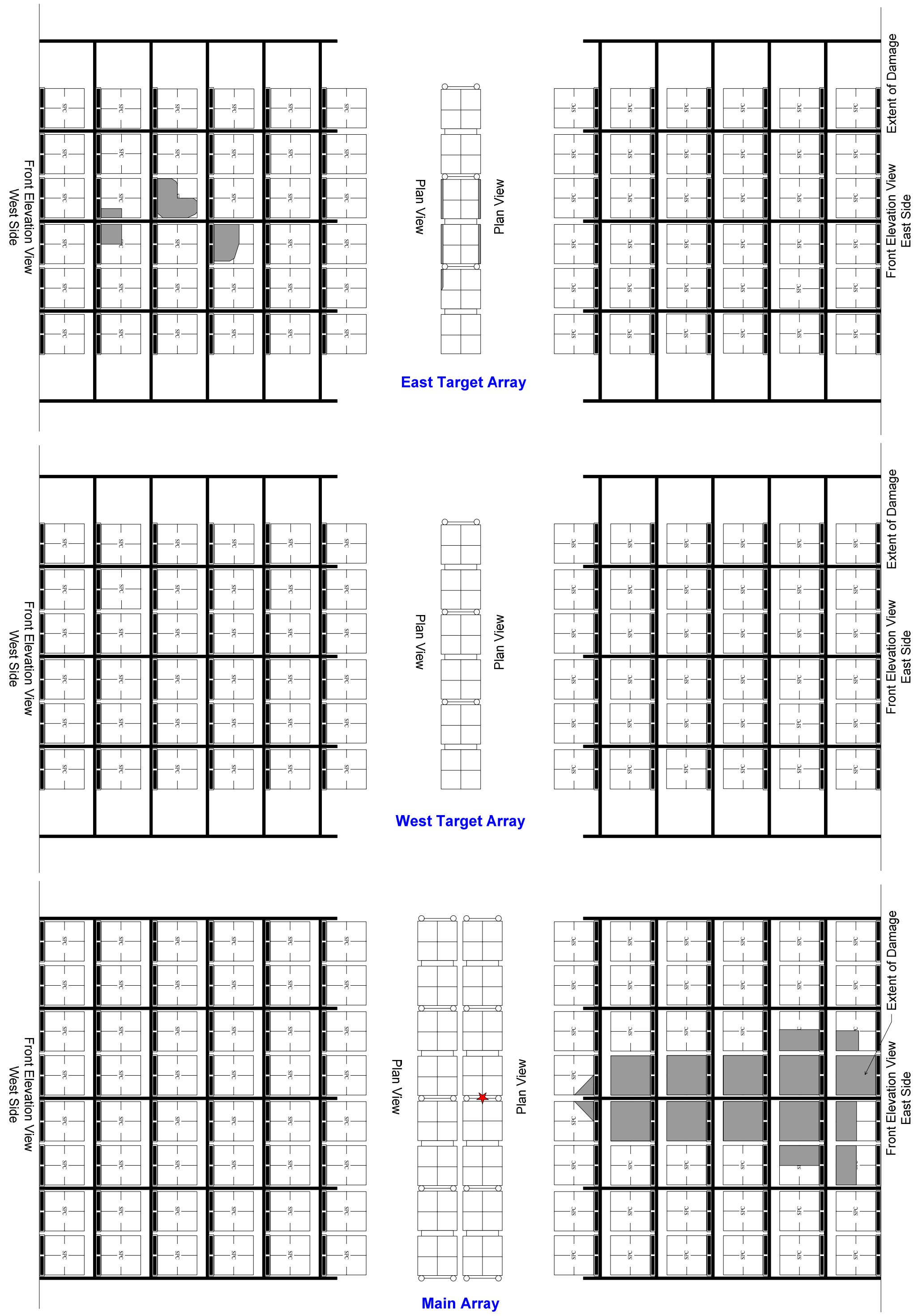
(Grey shaded areas indicate damaged pallet loads)

Figure 7. Test 1 Damage Diagram (Courtesy of FM Global)



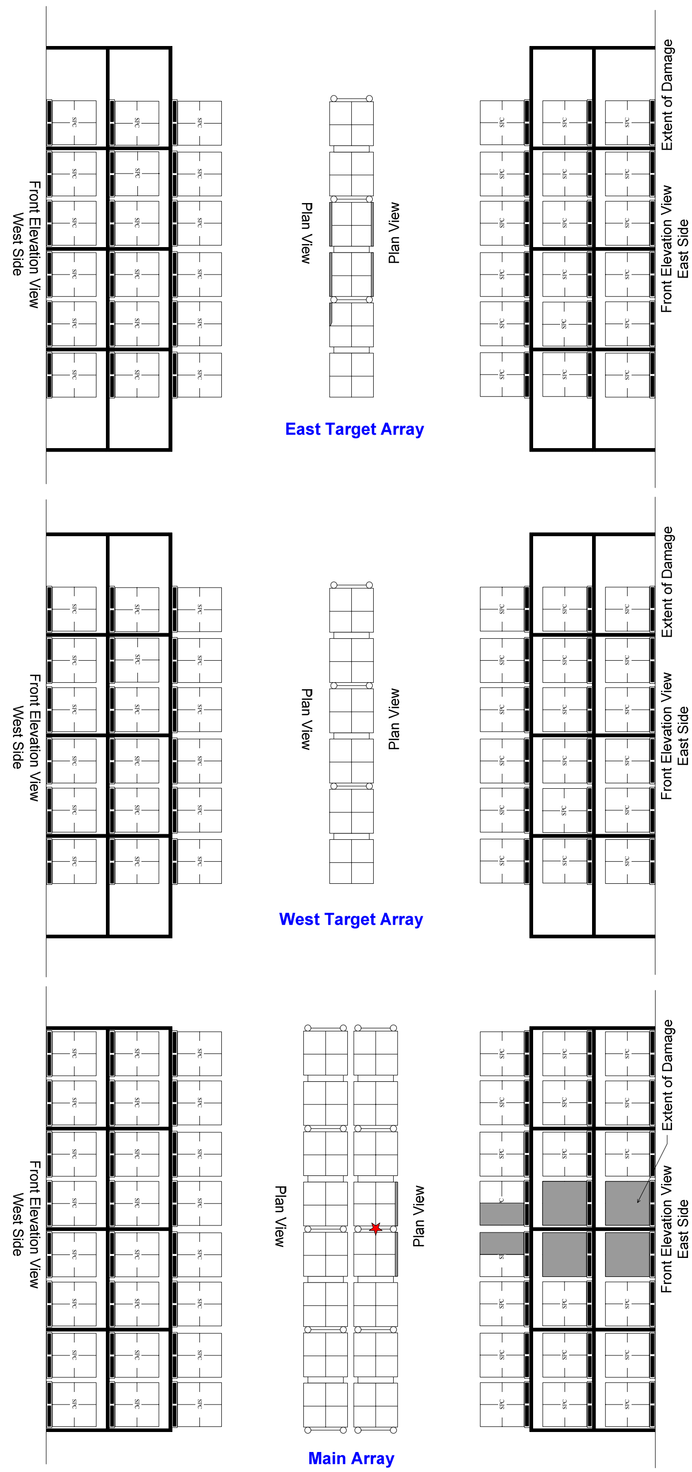
(Grey shaded areas indicate damaged pallet loads)

Figure 8. Test 2 Damage Diagram (Courtesy of FM Global)



(Grey shaded areas indicate damaged pallet loads)

Figure 9. Test 3A Damage Diagram (Courtesy of FM Global)



(Grey shaded areas indicate damaged pallet loads)

Figure 10. Test 3B Damage Diagram (Courtesy of FM Global)

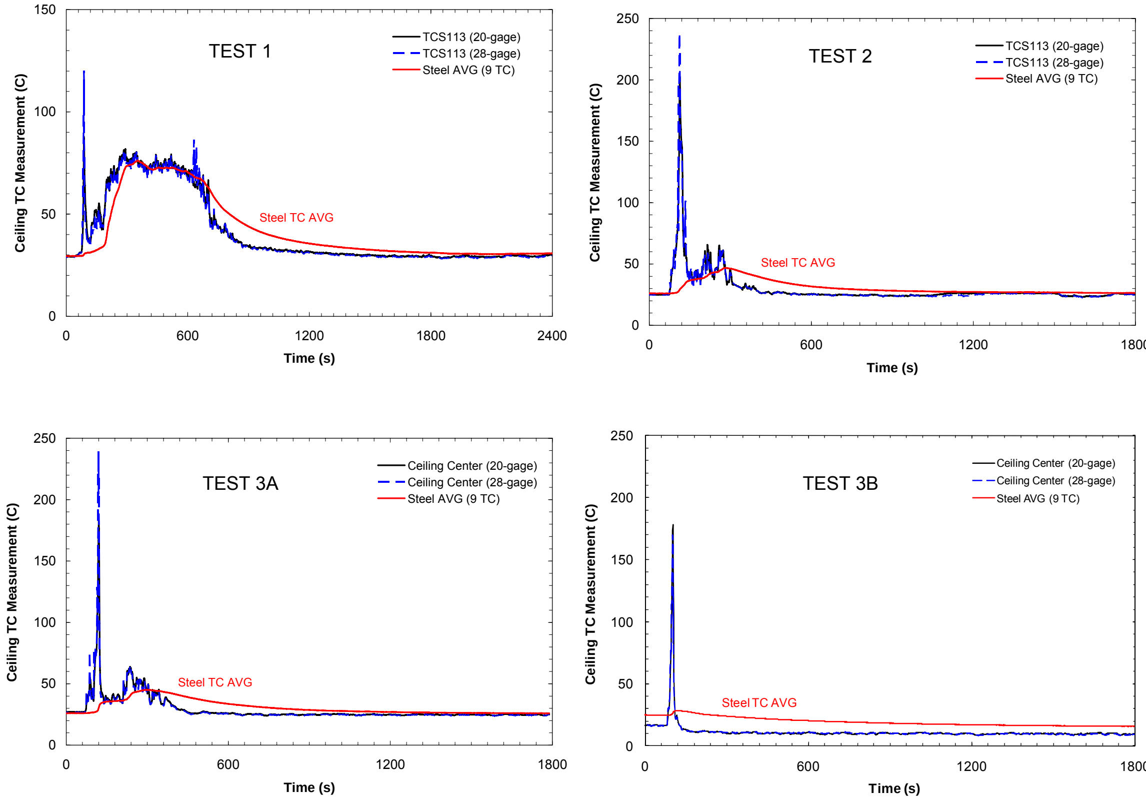


Figure 11. Tests 1-3B Steel Temperature Measurements (Courtesy of FM Global)

The remaining three ESFR sprinkler tests were conducted in the Underwriters Laboratories large scale fire test facility located in Northbrook, Illinois.

During Test 4 (UL-1), six ESFR sprinklers activated, the first occurring at 1 minute and 21 seconds, the last at 1 minute and 47 seconds. The fire did not spread beyond the ignition array or to the target arrays. Damage was calculated as 25 equivalent pallets. The peak one minute average ceiling temperature was 100 degrees F, which is below the critical value of 1,000 degrees F. This test was considered acceptable based upon the previously established pass/fail criteria.

Test 5 (UL-2) was a repeat of Test 4 (UL-1), only the ignition location was moved to under the fan hub. Again, six ESFR sprinklers operated, with the first activating at 1 minute and 05 seconds and the last at 1 minute and 57 seconds. The fire did not spread beyond the ignition array or to the target arrays. Damage was calculated as 23 equivalent pallets and the damage pattern was very similar to Test 4 (UL-1). The peak one minute average ceiling temperature was 105 degrees F, which is below the critical value of 1,000 degrees F. This test was considered acceptable based upon the previously established pass/fail criteria.

The success of the ESFR palletized testing resulted in speculation that fan affect on sprinkler system performance was influenced more by fan characteristics, such as blade number or orientation, than the characteristics of the array. In an effort to explore this theory, XL GAPS conducted a full-scale fire test (Test 9) on November 11, 2010 at the Underwriters Laboratories large scale fire test facility located in Northbrook, Illinois. Test 9 (UL-6), duplicated Test 4 (UL-1) except that a Rite-Hite Revolution 24-foot diameter, 4 blade, 48 RPM HVLS fan was used in lieu of the MaxAir Whisperfoil XL 24-foot diameter, 6 blade, 64 RPM HVLS fan. The Rite-Hite Revolution fan was the same model used in the 2007 XL GAPS Test 1 (CMDA sprinklers) and was operated at 64 RPM the entire duration of the test.

Comparison of the preliminary data from the two tests showed minimal difference; the number of sprinklers which operated increased by two (6 versus 8), sprinkler response was reduced (from 1 minute 21 seconds to 56 seconds), and maximum one minute ceiling temperatures increased slightly (from 102 degrees F to 131 degrees F). The fire did not burn beyond the ignition array and 28 equivalent pallets were consumed versus 25 equivalent pallets in Test 5[7]. This test was considered acceptable based upon the previously established criteria.

Review of the ESFR palletized storage test data showed that the location of the fan relative to the ignition location had little affect on the performance of the ESFR sprinklers based upon a comparison of the number of operating sprinklers, sprinkler activation times, ceiling temperatures, and commodity consumed. ESFR sprinkler performance was acceptable in all palletized tests, which is consistent with previous testing of this array.

Additionally, results showed the change in fan model did not influence the performance of the sprinklers in a substantial manner. A summary of the ESFR sprinkler palletized storage tests, along with sprinkler activation diagrams, damage diagrams, and steel temperature diagrams are shown in the following table and figures.

[7] Preliminary Data Provided at the Courtesy of Pete Willse of XL GAPS.

Table 2. Results for Tests 4, 5, and 9

FIRE TESTS	FPRF Test 4 (UL-1) 9/15/2010	FPRF Test 5 (UL-2) 9/17/2010	FPRF Test 9 (UL-6) 11/12/2010
PARAMETERS			
Location of Test	U.L.	U.L.	U.L.
Storage Type	Palletized Open Array	Palletized Open Array	Palletized Open Array
Commodity Type	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic
Nominal Storage Height (ft)	15	15	15
Nominal Ceiling Height (ft)	40	40	40
Nominal Clearance (ft)	25	25	25
Aisle Width (in.)	N/A	N/A	N/A
Longitudinal/Transverse Flue (in.)	12	12	12
Ignition Location	Between 4 Sprinklers (centered)	Between 4 Sprinklers (centered)	Between 4 Sprinklers (centered)
Igniter Details	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline
Sprinkler Type/Temperature Rating (°F)	ESFR/165	ESFR/165	ESFR/165
Sprinkler Orientation	Pendent	Pendent	Pendent
Sprinkler Sensitivity	Fast Response	Fast Response	Fast Response
Sprinkler Make/Model Number	Tyco/ESFR-1	Tyco/ESFR-1	Tyco/ESFR-1
Deflector to Ceiling (in.)	14	14	14
Nominal Sprinkler Discharge Coefficient K (gpm/psi½)	14	14	14
Density/Nominal Sprinkler Discharge Pressure (psi)	75	75	75
Sprinkler Spacing (ft x ft)	10 x 10	10 x 10	10 x 10
Fan Size (ft)	24	24	24
Fan Location	Fan Tip 2 ft Beyond Ignition	Hub Above Ignition	Fan Tip 2 ft Beyond Ignition
Fan Distance Below Ceiling (in.)	54.5	54.5	72
HVLS Fan Speed (rpm)	63	63	64
HVLS Fan Operation	On (no shutdown)	On (no shutdown)	On (no shutdown)
HVLS Fan Manufacturer	MacroAir	MacroAir	Rite-Hite
HVLS Fan Model Name	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL	Revolution
HVLS Fan Model Number	MA24XL2006	MA24XL2006	-
HVLS Fan Blade Geometry	Whisperfoil XL	Whisperfoil XL	Propell-Aire Standard
HVLS Fan Number of Blades	6	6	4
RESULTS			
Length of Test (hr:min:s)	0:30:00	0:30:00	0:30:00
First Ceiling Sprinkler Operation (min:s)	1:21	1:05	0:56
Last Ceiling Sprinkler Operation (min:s)	1:47	1:57	1:51
Number of Operated Ceiling Sprinklers	6	6	8
Peak Gas Temperature at Ceiling Above Ignition (°F)	207	181	181
Max. 1 Min. Average Gas Temp. at Ceiling Above Ignition (°F)	131	154	131
Peak Steel Temperature at Ceiling Above Ignition (°F)	102	118	121
Max. 1 Min. Average Steel Temp. Above Ignition (°F)	100	105	116
Fire Spread Across Aisle	NO	NO	NO
Fire spread to the Ends of the Array	NO	NO	NO
Fuel Consumed (number of pallets)	25	23	28
Test Outcome (Pass/Fail)	PASS	PASS	PASS
Comments			Repeat of Test 4 using different fan model

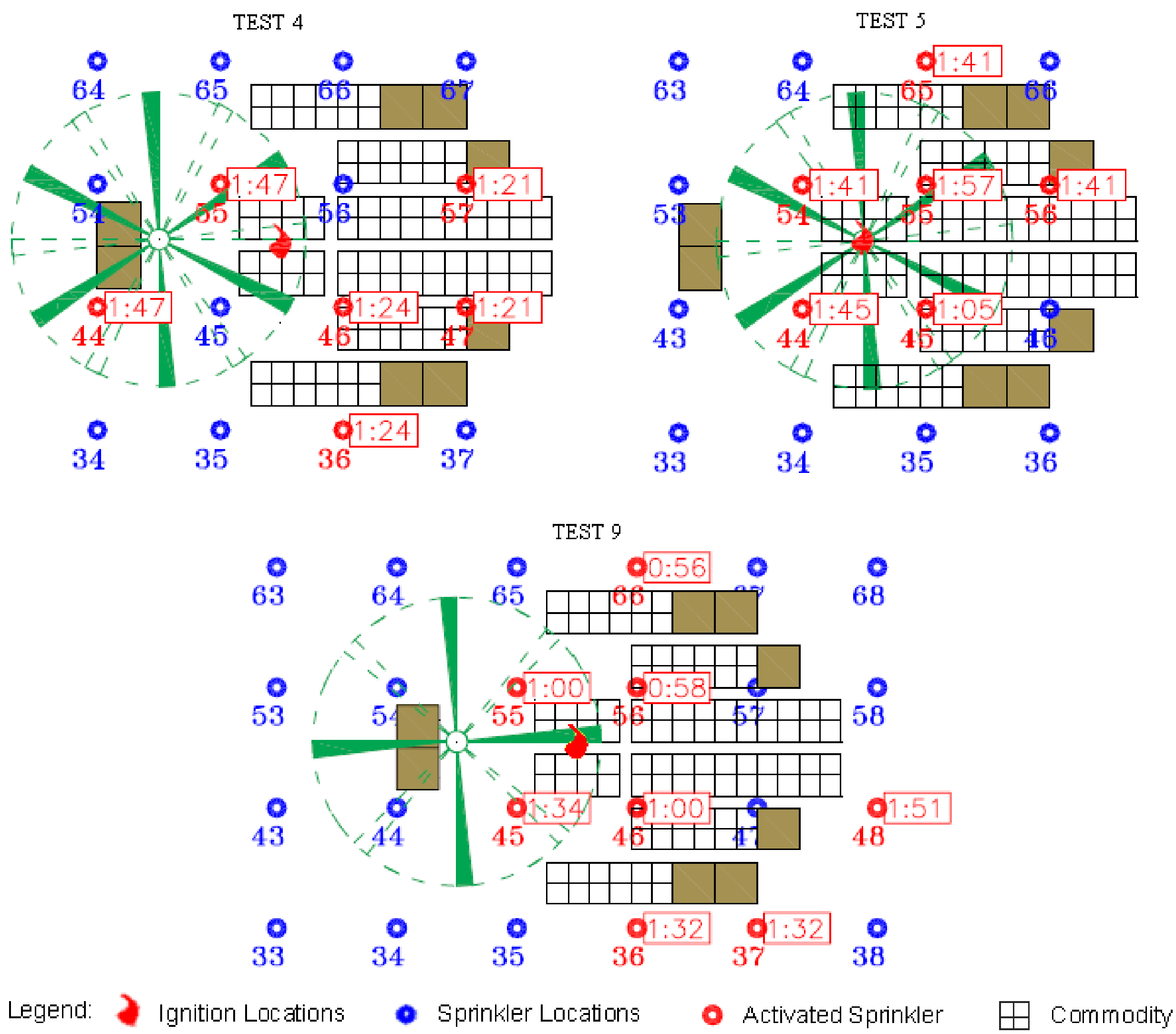


Figure 12. Tests 4, 5, and 9 Sprinkler Operation (Courtesy of UL)

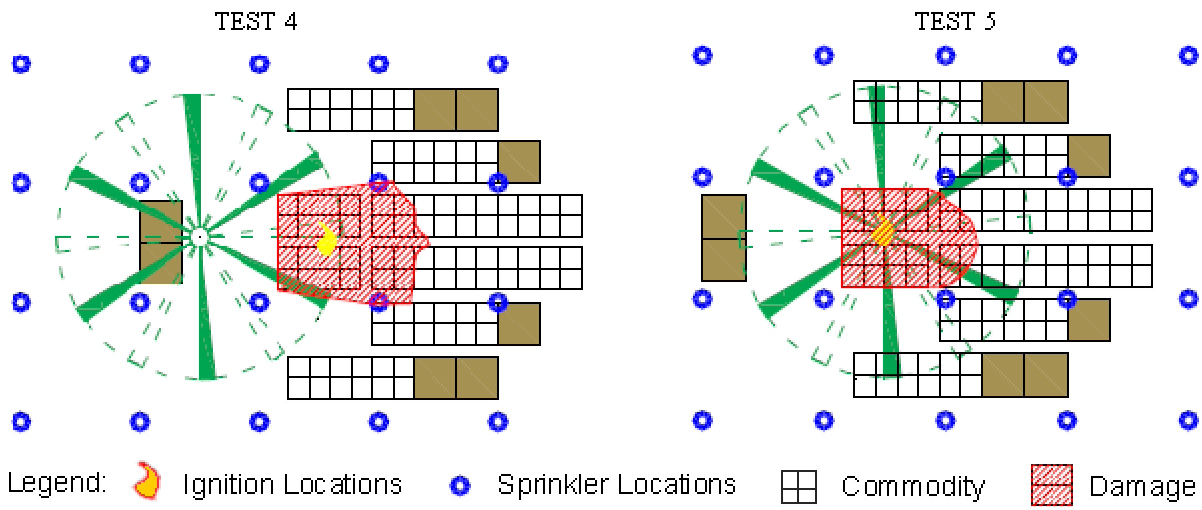


Figure 13. Tests 4 and 5 Damage Diagrams (Courtesy of UL)

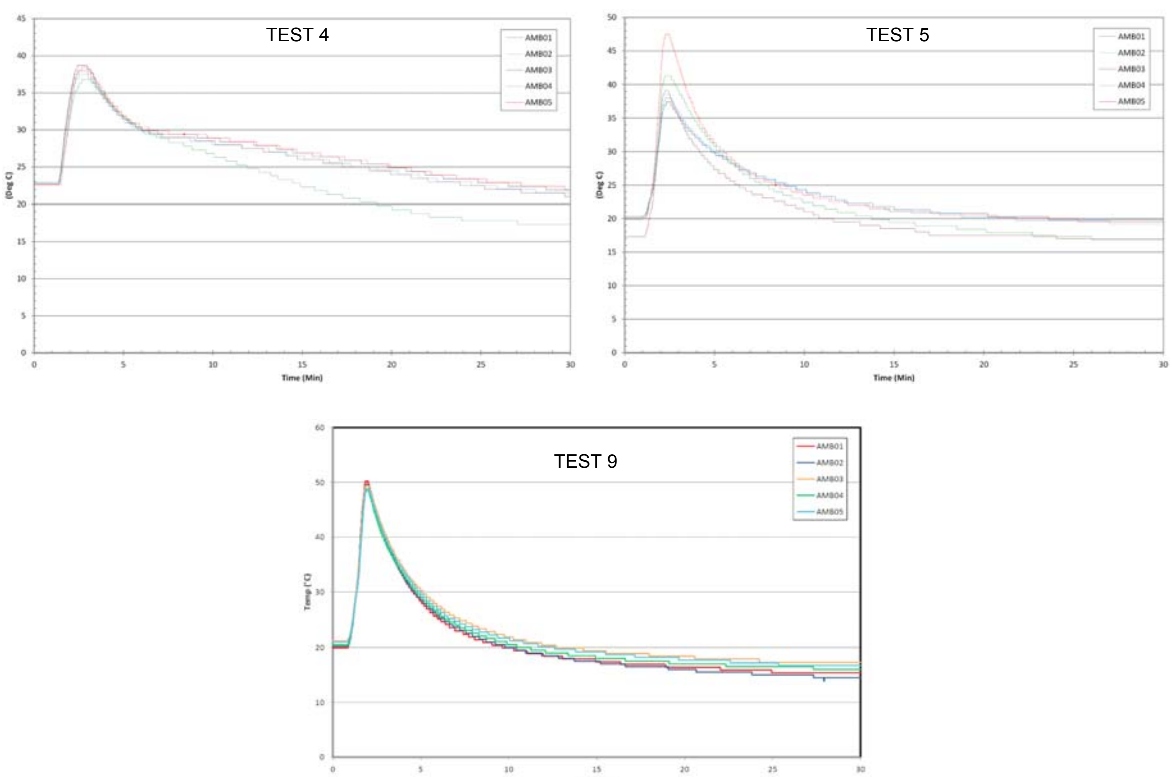


Figure 14. Tests 4, 5, and 9 Steel Temperature Measurements (Courtesy of UL)

CMDA Sprinkler Testing

Three CMDA sprinkler tests were conducted in the Underwriters Laboratories large scale fire test facility located in Northbrook, Illinois. Palletized storage array was used for all tests.

In Test 6 (UL-3), six sprinklers activated; the first occurring at 1 minute and 36 seconds, the last at 1 minute and 58 seconds. The air sampling-type detector activated at 1 minute and 36 seconds, immediately upon which the fan was de-energized.

The fire did not spread to the end of the main array or to the target arrays. Damage was calculated as 26 equivalent pallets. The peak one minute average ceiling temperature was 219 degrees F, which is below the critical value of 1,000 degrees F.

Ceiling temperature data showed that once the maximum temperature was reached, the six sprinklers that activated nearly in unison (within 22 seconds of the first) temporarily quelled the fire's intensity. A small re-growth period occurred followed by the slow decay of the heat-release rate. This test was considered acceptable based upon the previously established pass/fail criteria. Since the air sampling-type detector and the first sprinkler activated concurrently, the fan shutdown time replicated the non-delayed waterflow shutdown of the 2007 XL GAPS Test 1.

Test 7 (UL-4) was a repeat of Test 6 (UL-3), only the ignition location was moved to under the fan hub. Seven sprinklers activated with the first activating at 2 minutes and 08 seconds and the last at 3 minutes and 28 seconds. The fan was shutdown by activation of the first ionization detector at 1 minute and 43 seconds. The air sampling-type detector Fire 1 signal occurred at 1 minute and 50 seconds. The fire did not spread to the end on the main array or to the target arrays. Damage was calculated as 15 equivalent pallets and the damage pattern was very similar to Test 6 (UL-3). The peak one minute average ceiling temperature was 360 degrees F, which is below the critical value of 1,000 degrees F. This test was considered acceptable based upon the previously established pass/fail criteria.

For Test 8 (UL-5), a departure from the test plan was made. The two previous fire tests were conducted specifically to find a solution to the unsuccessful sprinkler performance of the 2007 XL GAPS Test 1. Both tests were a success, operating six or seven sprinklers each and showing no signs of the disastrous performance of the XL GAPS test. Fan shutdown by the air sampling-type detector and spot smoke detectors were effective. However, a more simplistic and lower-cost alternate would be to shut the fan down upon sprinkler activation. Additionally, previous testing of CMDA sprinkler protection of rack storage array was successful; repeating a rack storage array test would be of marginal value.

With this direction in mind, Test 8 (UL-5) was a repeat of Test 6 (UL-3) with the fan at full speed until the operation of the first sprinkler. Then, after a 90-second delay, the fan was de-energized. Twenty sprinklers activated with the first activating at 1 minute and 13 seconds and the last at 3 minutes and 01 seconds. For data collection purposes, the response of the ionization detectors and the air sampling-type detector were recorded. The first ionization detector activated at 51 seconds. The air sampling-type detector Fire 1 signal occurred at 1 minute and 19 seconds. The fire did not spread to the end of the main array or to the target arrays. Damage was calculated as 32 equivalent pallets and the damage pattern was very similar to Test 6 (UL-3). The peak one minute average ceiling temperature was 327 degrees F, which is below the critical value of 1,000 degrees F. This test was considered acceptable based upon the previously established pass/fail criteria.

The drastically different outcome of Tests 6-8 (UL-3-5) in comparison to that of the 2007 XL GAPS Test 1 was puzzling. In an attempt to explain the unique results of the latter, an extensive review of numeric data, visual media, and other material was completed.

Review of the sprinkler discharge pressures of the 2007 XL GAPS Test 1 (Figure 15) showed that the pressure required to provide a 0.60 gpm/sq.ft sprinkler density, 18 psi, was provided when the first two sprinklers simultaneously activated at 3:26 minutes. However, after that point the water pressure decayed so that the next three sprinklers (which operated at 3:28, 3:39, and 3:42 minutes) were provided with a reduced pressure in the range of 8-14 psi. This resulted in sprinkler densities of approximately 0.40-0.52 gpm/sq.ft for these sprinklers. The water pressure increased back to 18 psi, but again another decrease in pressure below 18 psi occurred at approximately 4:15 minutes. This fluctuation of the water pressure resulted in the sprinkler densities below that establish for the testing.

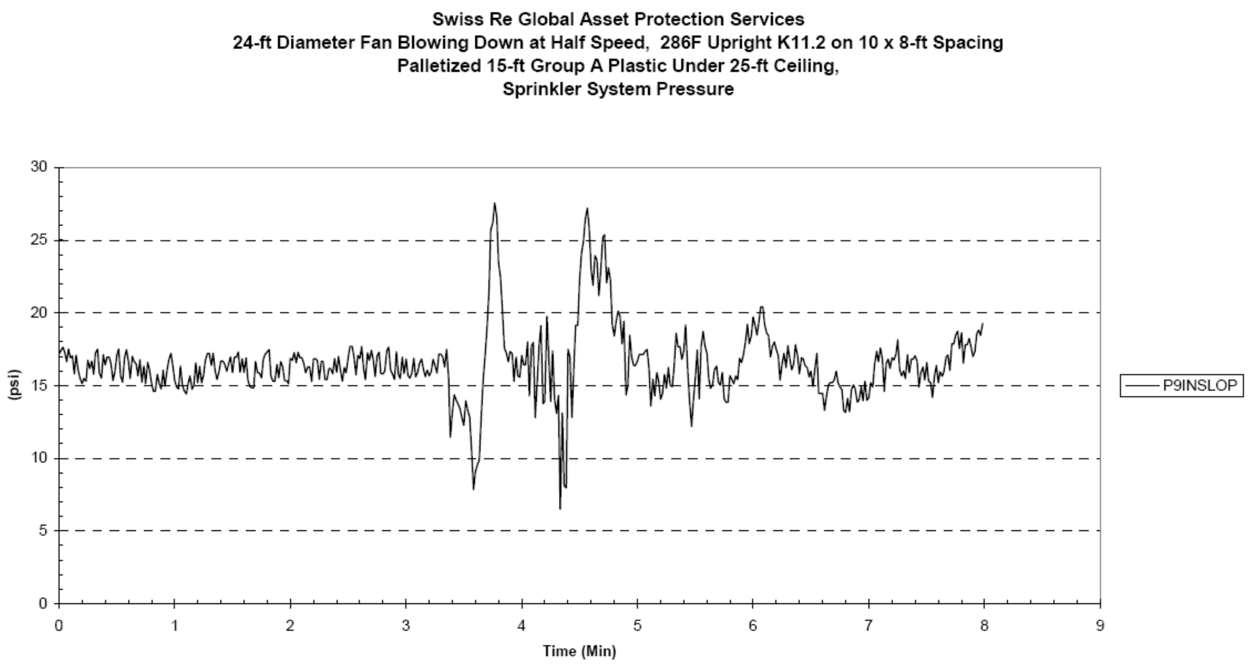


Figure 15. 2007 XL GAPS Test 1 Sprinkler Pressures (Courtesy of UL)

A reduction in total sprinkler flow also occurred during this period (Figure 16). Review of sprinkler flow data for Tests 6-8 (UL-3-5) showed no such decrease in flow (sprinkler pressure data was not provided).

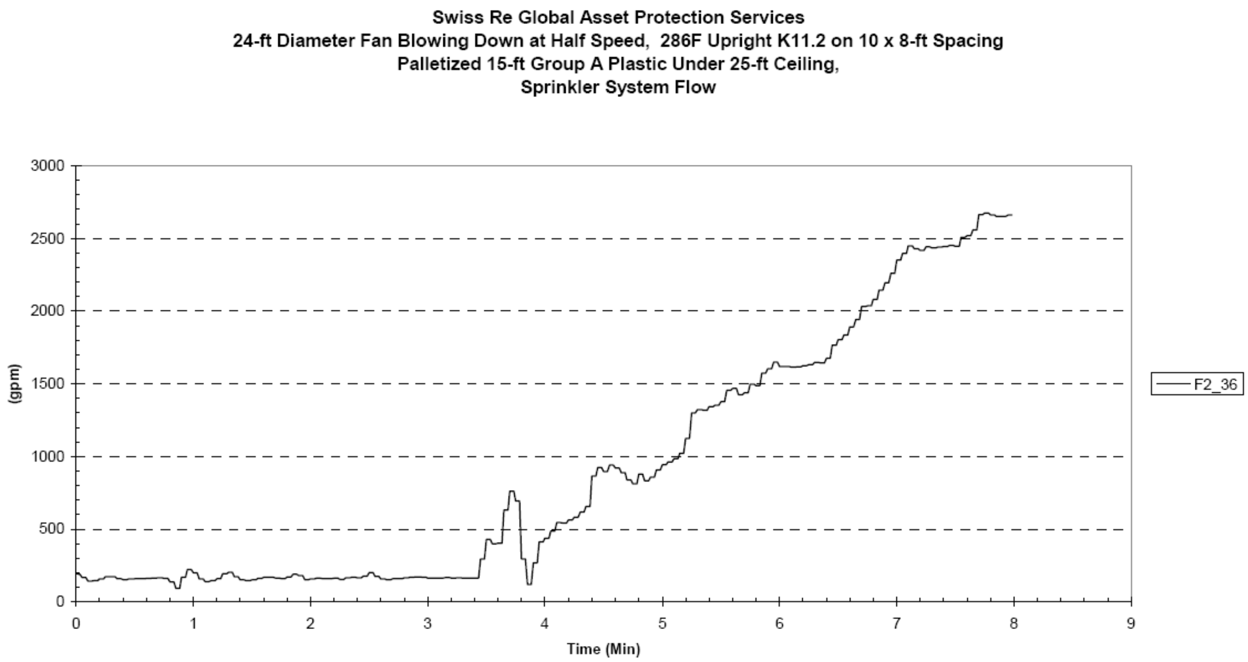


Figure 16. 2007 XL GAPS Test 1 Sprinkler System Flow (Courtesy of UL)

Another difference discovered between the subject tests was the igniters used. In Tests 6-8, two standard igniters were used (e.g., two 3-inch by 6-inch long cellulosic bundles soaked in 8 ounces of gasoline wrapped in a polyethylene bag). In the 2007 XL GAPS Test 1, two half igniters were used (e.g., two 3-inch by 3-inch long cellulosic bundles soaked in 4 ounces of gasoline wrapped in a polyethylene bag). Use of smaller igniters could have prolonged the incipient phase of the fire, but would not substantially affect the fire size during early sprinkler operation.

The configuration of the tests was open array, with 12-inch wide longitudinal flue spaces. The influence of flue space width on rate of fire development and maximum heat-release rate was tested by the Swedish National Testing Research Institute. It was found that as the width of longitudinal flue spaces grows, there is reduced re-radiation from carton to carton and convective heat transfer to adjacent cartons is decreased. Especially during the incipient and fast upward fire spread periods of fire development, wider flue spaces greatly reduce the heat-release rate of a fire. However, during the take-off period of fire growth the heat release increases, due to the increased access to oxygen provided by the wider flues, resulting in a larger heat-release rate[8].

8 Ingason, H., 2003. Effects Of Flue Spaces On The Initial In-rack Plume Flow. Fire Safety Science.

Reduction in the incipient and upward fire spread period heat-release rate slows the vertical flame spread along the surfaces of the commodity within the flue space, delaying the flames from reaching the top of the array. It is possible that 12-inch flue spaces and the smaller igniters in the 2007 XL GAPS Test 1 prolonged the incipient phase of the fire and magnified the affect of the downward fan force. When sufficient heat finally accumulated at the ceiling to cause sprinkler activation, the fire size was significantly large, which hampered the ability of the sprinklers to control the fire.

Comparison of the ceiling temperature data of Tests 6-8 (UL-3-5) and the 2007 XL GAPS Test 1 showed no similarities. However, the data from the 2007 XL GAPS Test 1 (Figure 17) showed low initial temperatures until approximately 3 minutes at which time the temperature begins to rise, which is indicative of prolonged incipient and fast upward fire spread phases.

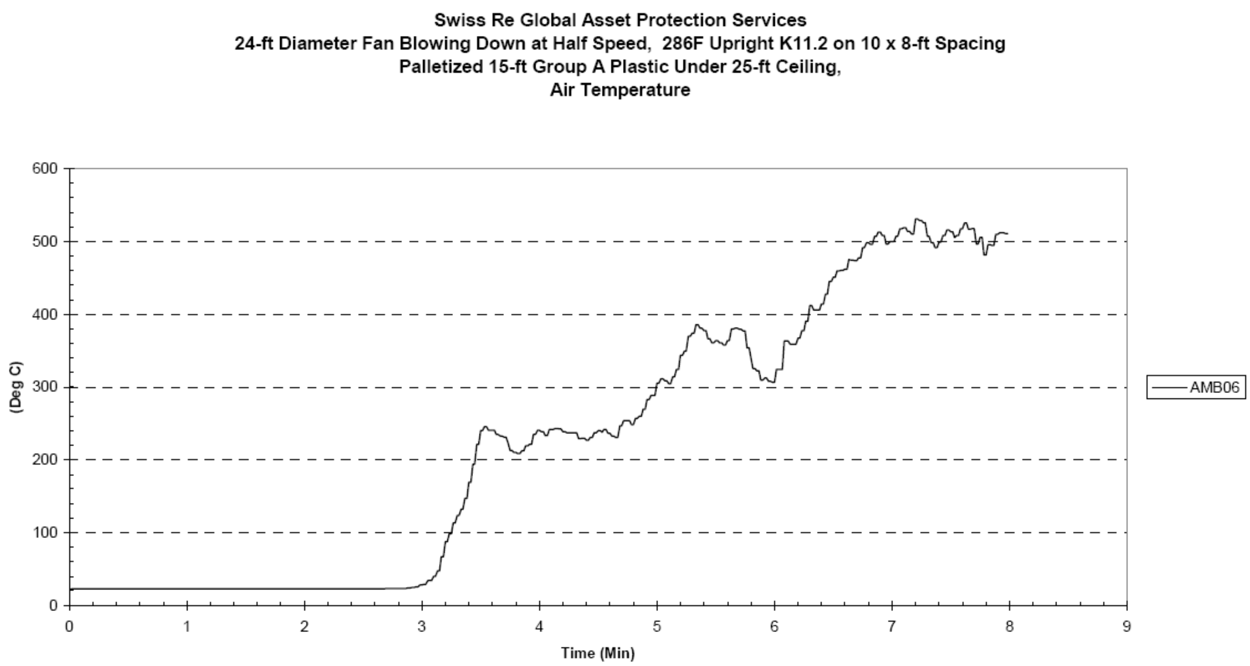


Figure 17. 2007 XL GAPS Test 1 Air Temperature (Courtesy of UL)

Due to the significant reduction in sprinkler density, smaller igniter size, and questions regarding other details of the test, the data from 2007 XL GAPS Test 1 was considered unreliable. Therefore, comparison to the results of Tests 6-8 (UL-3-5) was of minimum value.

Review of the CMDA palletized storage testing data showed that the most challenging fan to ignition location was the fan tip 3-feet beyond the ignition location. The results also confirmed that the earlier the fan is shutdown, the less the fan negatively affects sprinkler performance. In Test 8 (UL-5), for example, the fan was de-energized at 163 seconds from ignition resulting in the activation of 20 sprinklers and the burning of 32 equivalent pallets. In Test 6 ((UL-3) the fan was shutdown at 96 seconds, 6 sprinklers operate, and 26 equivalent pallets were consumed.

A summary of the CMDA sprinkler palletized storage tests, along with sprinkler activation diagrams, damage diagrams, and steel temperature diagrams are shown in the following table and figures.

Table 3. Results for Tests 6-8

FIRE TESTS	FPRF Test 6 (UL-3) 9/21/2010	FPRF Test 7 (UL-4) 9/23/2010	FPRF Test 8 (UL-5) 9/28/2010
PARAMETERS			
Location of Test	U.L.	U.L.	U.L.
Storage Type	Palletized Open Array	Palletized Open Array	Palletized Open Array
Commodity Type	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic
Nominal Storage Height (ft)	15	15	15
Nominal Ceiling Height (ft)	25	25	25
Nominal Clearance (ft)	10	10	10
Aisle Width (in.)	N/A	N/A	N/A
Longitudinal/Transverse Flue (in.)	12	12	12
Ignition Location	Between 4 Sprinklers (centered)	Between 4 Sprinklers (centered)	Between 4 Sprinklers (centered)
Igniter Details	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline
Sprinkler Type/Temperature Rating (°F)	CMDA/286	CMDA/286	CMDA/286
Sprinkler Orientation	Upright	Upright	Upright
Sprinkler Sensitivity	Std. Response	Std. Response	Std. Response
Sprinkler Make/Model Number	Tyco/ELO-231-B	Tyco/ELO-231-B	Tyco/ELO-231-B
Deflector to Ceiling (in.)	3	3	3
Nominal Sprinkler Discharge Coefficient K (gpm/psi½)	11.2	11.2	11.2
Density/Nominal Sprinkler Discharge Pressure (psi)	0.60 gpm/sq ft	0.60 gpm/sq ft	0.60 gpm/sq ft
Sprinkler Spacing (ft x ft)	8 x 10	8 x 10	8 x 10
Fan Size (ft)	24	24	24
Fan Location	Fan Tip 3 ft Beyond Ignition	Hub 1 ft West of Ignition	Fan Tip 3 ft Beyond Ignition
Fan Distance Below Ceiling (in.)	54.5	54.5	54.5
HVLS Fan Speed (rpm)	63	63	63
HVLS Fan Operation	Off at Air Sampling-Type Detection (1:36) (no delay)	Off at Ion Smoke Detector Operation (1:43) (no delay)	Off at Waterflow (90 sec delay)
HVLS Fan Manufacturer	MacroAir	MacroAir	MacroAir
HVLS Fan Model Name	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL
HVLS Fan Model Number	MA24XL2006	MA24XL2006	MA24XL2006
HVLS Fan Blade Geometry	Whisperfoil XL	Whisperfoil XL	Whisperfoil XL
HVLS Fan Number of Blades	6	6	6
RESULTS			
Length of Test (hr:min:s)	0:30:00	0:30:00	0:30:00
First Ceiling Sprinkler Operation (min:s)	1:36	2:08	1:13
Last Ceiling Sprinkler Operation (min:s)	1:58	3:28	3:01
Number of Operated Ceiling Sprinklers	6	7	20
Peak Gas Temperature at Ceiling Above Ignition (°F)	1468	504	1506
Max. 1 Min. Average Gas Temp. at Ceiling Above Ignition (°F)	1042	360	1287
Peak Steel Temperature at Ceiling Above Ignition (°F)	244	122	415
Max. 1 Min. Average Steel Temp. Above Ignition (°F)	219	122	410
Fire Spread Across Aisle	NO	NO	NO
Fire spread to the Ends of the Array	NO	NO	NO
Fuel Consumed (number of pallets)	26	15	32
Test Outcome (Pass/Fail)	PASS	PASS	PASS
Comments		Fan blades failed (bent) after shutdown	

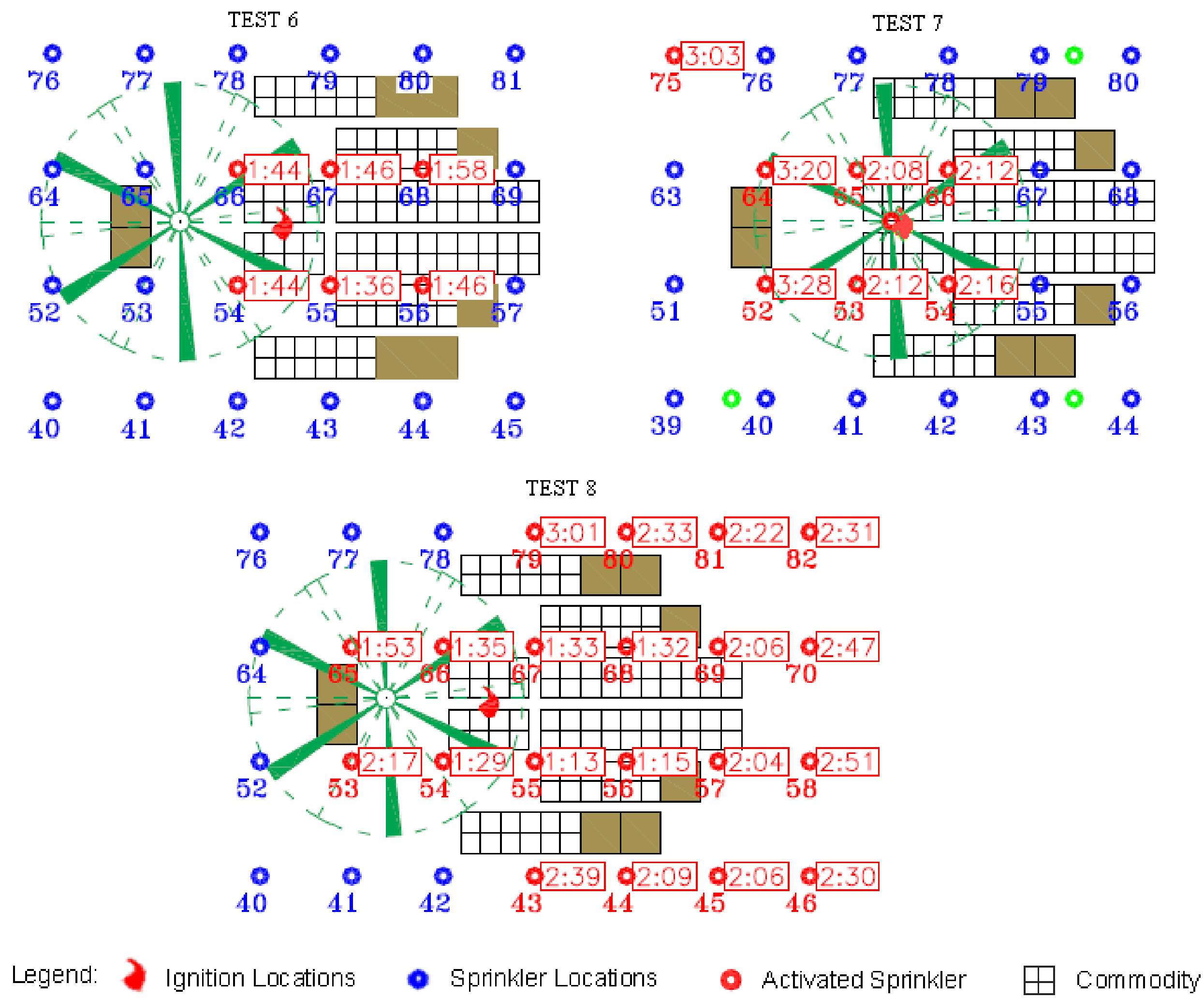


Figure 18. Tests 6-8 Sprinkler Operation (Courtesy of UL)

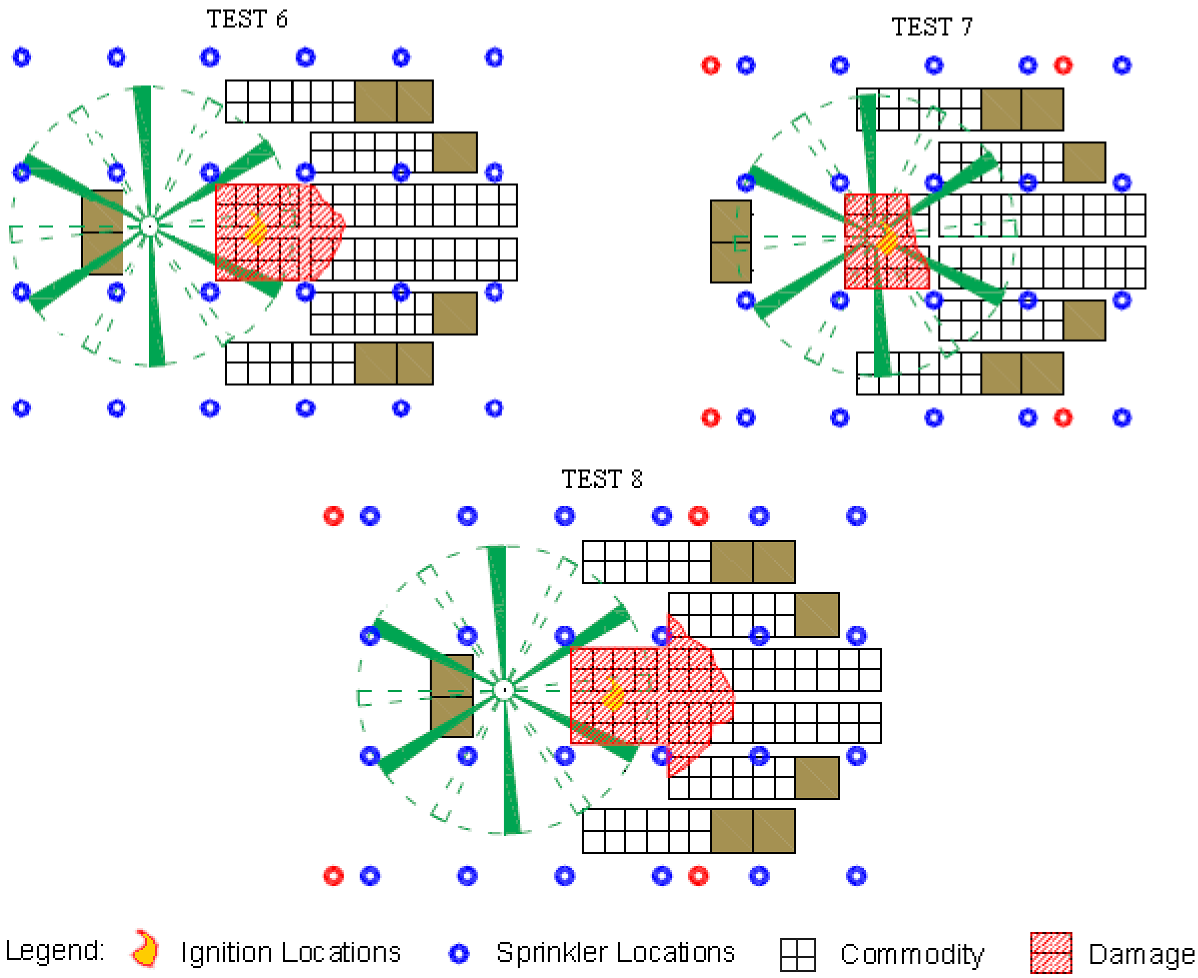


Figure 19. Tests 6-8 Damage Diagrams (Courtesy of UL)

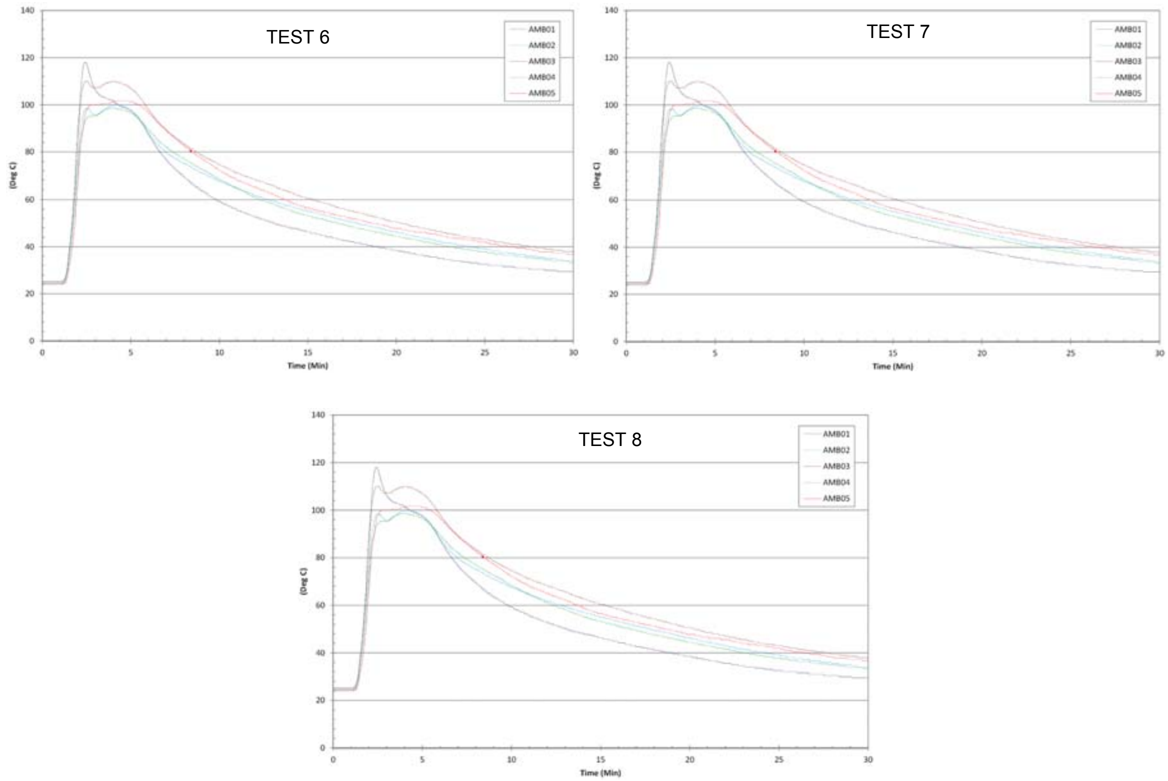


Figure 20. Tests 6-8 Steel Temperature Measurements (Courtesy of UL)

Velocity Measurements

Velocity data was gathered as part of this study in an attempt to understand air movement through each array. Vertical velocity profiles were generated by FM Global for the rack storage arrays measured at 5 inches above the top of the main array. Horizontal velocity data was provided by UL for the palletized storage arrays at the end of the five flue spaces. Detailed data obtained can be found in Appendix C and D.

The velocity data provided by FM Global confirmed that the manufacturer's results for fastest air speeds were located at ½-⅔ the length of the blade (from the center of the fan). Data within the rack storage array was gathered by FM Global but has not been released at this time.

The velocity data provided by Underwriters Laboratory was measured at 5 feet, 10 feet, and 15 feet above the floor at the end of each flue space (between approximately 17 feet and 29 feet from the fan hub depending on the fan location and the flue space being measured). Velocity data was gathered with and without the storage in place.

Horizontal velocity data without the storage in place revealed the maximum average velocity was 4.23 ft/s at a distance of approximately 17 feet from the fan hub at 5 feet above the floor level. Forty of the 50 velocity measurements taken at 10 and 15 feet above the floor were negative. The negative velocity measurements represented air movement toward the fan.

Horizontal velocity data also showed the fastest horizontal velocities occurred at 5 feet from the floor level when storage was in place. The fastest average air speed was measured to be 12.88 ft/s. This value was over three times the average velocity without the storage in place.

CONCLUSION

The objective of the Phase II research effort was to expand the investigation of the impact of HVLS fans on the performance of automatic sprinklers. Phase II included both ESFR and CMDA sprinklers and rack and palletized storage arrays.

Ten full scale tests were completed, four tests in the Large Burn Lab of the Fire Laboratory at the FM Global Research Campus located in West Glocester, Rhode Island and six tests at Underwriters Laboratories large scale fire test facility located in Northbrook, Illinois.

K14 ESFR sprinklers protecting both rack storage and palletized storage arrays were tested. The boundary condition used for all the ESFR tests was a 40-foot ceiling, the maximum allowed by current design standards. A storage height of 30 feet was used for three of the four rack storage tests, the tallest possible given the required clearance of 5 feet above and below the fan. One rack storage test was also completed with a storage height of 15 feet to test a high-clearance condition, 25 feet from ceiling to top of storage. Cartoned, unexpanded Group A plastic commodity was used for all tests. The ESFR palletized storage tests used a storage height of 15 feet to simulate conditions found within picking and receiving areas where handling of product was the priority, not maximization of storage density.

Review of the ESFR rack storage testing data showed the most challenging fan to ignition location was with the fan hub centered over ignition. This is consistent with the Phase I FPRF work. ESFR sprinkler performance was acceptable when the fan was de-energized 90 seconds after waterflow from the first operating sprinkler.

Review of the ESFR palletized storage test data showed that the location of the fan relative to the ignition location had little affect on the performance of the ESFR sprinklers based upon a comparison of the number of operating sprinklers, sprinkler activation times, ceiling temperatures, and commodity consumed. ESFR sprinkler performance was acceptable in all palletized tests, which is consistent with previous testing of this array.

Three CMDA sprinkler tests were conducted at the Underwriters Laboratories large scale fire test facility located in Northbrook, Illinois. The highest storage and ceiling heights allowed by current design standards, 15 feet and 25 feet respectively, were selected for these tests and palletized storage array was used. CMDA sprinkler performance was acceptable when the fan was de-energized 90 seconds after water flow from the first operating sprinkler, from air sampling-type detector activation, or at ionization smoke detector activation.

From the fire tests conducted, the following conclusions can be made:

1. K14 ESFR sprinklers can adequately protect cartoned, unexpanded Group A plastic in double row rack storage array to a height of 30 feet beneath a 40-foot ceiling in the presence of HVLS fans when the fans are shutdown no later than 90 seconds after waterflow of the first operating sprinkler.
2. K14 ESFR sprinklers can adequately protect cartoned, unexpanded Group A plastic in palletized storage array to a height of 15 feet beneath a 40-foot ceiling in the presence of HVLS fans operating.
3. K11.2 CMDA sprinklers can adequately protect cartoned, unexpanded Group A plastic in palletized storage array to a height of 15 feet beneath a 25-foot ceiling in the presence of HVLS fans when the fans were shutdown no later than 90 seconds after waterflow of the first operating sprinkler.

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APPENDIX A – SUMMARY OF PREVIOUS HVLS FAN TESTING

SUMMARY OF PREVIOUS HVLS FAN TESTING 1/27/11

FIRE TEST	FPRF 10/8/2008	FPRF 10/10/2008	XL GAPS 6/1/2009	XL GAPS 6/1/2009	XL GAPS (Test 1) 2007	XL GAPS (Test 2) 2007	XL GAPS (Test 3) 2007	BIG FAN 5/5/2008	BIG FAN 5/7/2008	BIG FAN 9/11/2008
PARAMETERS										
Location of Test	U.L.	U.L.	U.L.	U.L.	U.L.	U.L.	U.L.	Southwest	Southwest	Southwest
Storage Type	Double-Row Rack	Double-Row Rack	Double-Row Rack	Double-Row Rack	Palletized Open Array	Palletized Open Array	Palletized Open Array	Palletized Open Array	Palletized Open Array	Palletized Open Array
Commodity Type	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic	Standard Class II Commodity	Standard Class II Commodity	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic
Nominal Storage Height (ft)	20	20	15	15	15	12	12	15	15	15
Nominal Ceiling Height (ft)	30	30	25	25	25	22	22	26	26	26
Nominal Clearance (ft)	10	10	10	10	10	10	10	11	11	11
Aisle Width (in.)	48	48	96	96	NA	NA	NA	NA	NA	NA
Longitudinal/Transverse Flue (in.)	6-Jun	6-Jun	6-Jun	6-Jun	12	6	6	12	12	12
Ignition Location	Between 2 Sprinklers	Between 4 Sprinklers	Between 4 Sprinklers	Between 4 Sprinklers	Between 4 Sprinklers	Between 4 Sprinklers	Between 4 Sprinklers	Between 4 Sprinklers	Between 4 Sprinklers	Between 4 Sprinklers
Igniter Details	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline	2 Half Igniters - 3" by 3" Each with 4 oz Gasoline	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline
Sprinkler Type/Temperature Rating (°F)	ESFR/165	ESFR/165	CMDA/286	CMDA/286	CMDA/286	CMDA /165	CMDA /165	ESFR/165	ESFR/165	ESFR/165
Sprinkler Orientation	Pendent	Pendent	?	?	Upright	Upright	Upright	?	?	?
Sprinkler Sensitivity	Fast Response	Fast Response	Std. Response	Std. Response	?	?	?	Fast Response	Fast Response	Fast Response
Sprinkler Make/Model Number	Tyco/ESFR-1	Tyco/ESFR-1	?	?	?	?	?	Viking VK500	Viking VK500	Viking VK500
Deflector to Ceiling (in.)	14	14	12	12	3	2	3	12	12	12
Nominal Sprinkler Discharge Coefficient K $(gpm/psi^{1/2})$	14	14	11.2	11.2	11.2	5.6	5.6	14	14	14
Density/Nominal Sprinkler Discharge Pressure (psi)	50	50	0.60 gpm/sq ft	0.60 gpm/sq ft	0.60 gpm/sq ft	0.20 gpm/sq ft	0.20 gpm/sq ft	50	50	50
Sprinkler Spacing (ft x ft)	10 x 10	10 x 10	10 x 10	10 x 10	8 x 10	10 X 12	10 X 12	10 x 10	10 x 10	10x10
Fan Size (ft)	24	24	24	24	24	NA	24	NA	20	20
Fan Location	15-ft South of Ignition	Above Ignition	15-ft South of Ignition	15-ft South of Ignition	8-ft South of Ignition	NA	9-ft 10-in South of Ignition	NA	12-ft South of Ignition	12-ft South of Ignition
Fan Distance Below Ceiling (in.)	50	50	50	50	60	NA	60	NA	48	48
HVLS Fan Speed (rpm)	63	63	24	24	24	NA	24	NA	47	47
HVLS Fan Operation	On (no shutdown)	On (no shutdown)	Off at Sprinkler Operation	Off at Sprinkler Operation	Off at Sprinkler Operation	NA	On (no shutdown)	NA	Off at Sprinkler Operation	Off at Air Sampling-Type Detection Operation
HVLS Fan Manufacturer	MacroAir	MacroAir	?	?	?	NA	?	NA	Big Ass Fans	Big Ass Fans
HVLS Fan Model Name	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL	?	?	?	NA	?	NA	Powerfoil 20-foot	Powerfoil 20-foot
HVLS Fan Model Number	MA24XL2006	MA24XL2006	?	?	?	NA	?	NA	?	?
HVLS Fan Blade Geometry	Whisperfoil XL	Whisperfoil XL	Airfoil	Airfoil	Airfoil	NA	Airfoil	NA	Powerfoil	Powerfoil
HVLS Fan Number of Blades	6	6	4	4	4	NA	4	NA	10	10
PARAMETERS										
Length of Test (hr:min:s)	0:32:00	0:32:00	0:30:00	0:30:00	0:08:00	0:30:00	0:30:00	1:10:00	0:32:00	0:30:00
First Ceiling Sprinkler Operation (min:s)	1:00	0:49	1:56	1:53	3:26	1:14	1:57	1:31	2:00	1:50
Last Ceiling Sprinkler Operation (min:s)	1:04	4:48	5:34	3:31	7:35	3:40	3:51	2:16	2:45	1:58
Number of Operated Ceiling Sprinklers	2	8	9	10	73	21	26	4	4	4
Peak Gas Temperature at Ceiling Above Ignition (°F)	250	237	1335	1294	988	732	674	295	300	305
Maximum 1 Minute Average Gas Temperature at Ceiling Above Ignition (°F)	131	201	1083	1002	953	634	614	240	75	180
Peak Steel Temperature at Ceiling Above Ignition (°F)	109	145	378	471	519	289	346	130	220	135
Maximum 1 Minute Average Steel Temperature Above Ignition (°F)	106	142	309	295	408	288	344	125	75	120
Fire Spread Across Aisle	No	No	No	No	NA	NA	NA	NA	NA	NA
Fire spread to the Ends of the Array	No	No	No	No	Yes	No	Yes	No	No	No
Fuel Consumed (number of pallets)	?	?	?	?	?	?	?	?	?	?
Test Outcome (Pass/Fail)	PASS	PASS	PASS	PASS	FAIL	PASS	PASS	PASS	PASS	PASS
Comments					Test failed due to 73 sprinklers activating	Baseline Test- No Fan UL 199 (Ord Haz)	UL 199 (Ord Haz)	Baseline Test - No Fan		

Aon Fire Protection Engineering

APPENDIX B – FPRF HVLS FAN PHASE II TEST RESULTS SUMMARY

FPRF HVLS FAN PHASE II TEST RESULTS SUMMARY 1/27/11

FIRE TESTS	FPRF Test 1 (FM-1) 8/5/2010	FPRF Test 2 (FM-2) 8/20/2010	FPRF Test 3A (FM-3) 9/2/2010	FPRF Test 3B (FM-4) 12/2/2010	FPRF Test 4 (UL-1) 9/15/2010
PARAMETERS					
Location of Test	FM Global	FM Global	FM Global	FM Global	U.L.
Storage Type	Double-Row Rack	Double-Row Rack	Double-Row Rack	Double-Row Rack	Palletized Open Array
Commodity Type	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic
Nominal Storage Height (ft)	30	30	30	15	15
Nominal Ceiling Height (ft)	40	40	40	40	40
Nominal Clearance (ft)	10	10	10	25	25
Aisle Width (in.)	48	48	48	48	N/A
Longitudinal/Transverse Flue (in.)	6/6	6/6	6/6	6/6	12
Ignition Location	Under 1 Sprinklers (offset 2 ft)	Between 4 Sprinklers (offset 2 ft)	Between 4 Sprinklers (offset 2 ft)	Between 4 Sprinklers (offset 2 ft)	Between 4 Sprinklers (centered)
Igniter Details	2 Half Igniters - 3" by 3" Each with 4 oz Gasoline	2 Half Igniters - 3" by 3" Each with 4 oz Gasoline	2 Half Igniters - 3" by 3" Each with 4 oz Gasoline	2 Half Igniters - 3" by 3" Each with 4 oz Gasoline	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline
Sprinkler Type/Temperature Rating (°F)	ESFR/165	ESFR/165	ESFR/165	ESFR/165	ESFR/165
Sprinkler Orientation	Pendent	Pendent	Pendent	Pendent	Pendent
Sprinkler Sensitivity	Fast Response	Fast Response	Fast Response	Fast Response	Fast Response
Sprinkler Make/Model Number	Tyco/ESFR-1	Tyco/ESFR-1	Tyco/ESFR-1	Tyco/ESFR-1	Tyco/ESFR-1
Deflector to Ceiling (in.)	14	14	14	14	14
Nominal Sprinkler Discharge Coefficient K $(gpm/psi^{1/2})$	14	14	14	14	14
Density/Nominal Sprinkler Discharge Pressure (psi)	75	75	75	75	75
Sprinkler Spacing (ft x ft)	10 x 10	10 x 10	10 x 10	10 x 10	10 x 10
Fan Size (ft)	24	24	24	24	24
Fan Location	Fan Tip 4.9 ft Beyond Ignition	Hub Above Ignition (no offset)	Hub Above Ignition (no offset)	Hub Above Ignition (no offset)	Fan Tip 2 ft Beyond Ignition
Fan Distance Below Ceiling (in.)	50	50	50	50	54.5
HVLS Fan Speed (rpm)	66	66	66	66	63
HVLS Fan Operation	On (no shutdown)	On (no shutdown)	Off at Waterflow (90 sec delay)	Off at Waterflow (90 sec delay)	On (no shutdown)
HVLS Fan Manufacturer	MacroAir	MacroAir	MacroAir	MacroAir	MacroAir
HVLS Fan Model Name	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL
HVLS Fan Model Number	MA24XL2006	MA24XL2006	MA24XL2006	MA24XL2006	MA24XL2006
HVLS Fan Blade Geometry	Whisperfoil XL	Whisperfoil XL	Whisperfoil XL	Whisperfoil XL	Whisperfoil XL
HVLS Fan Number of Blades	6	6	6	6	6
RESULTS					
Length of Test (hr:min:s)	0:35:00	0:25:00	0:30:00	0:30:00	0:30:00
First Ceiling Sprinkler Operation (min:s)	1:28	1:42	1:54	1:39	1:21
Last Ceiling Sprinkler Operation (min:s)	7:53	3:57	2:03	1:42	1:47
Number of Operated Ceiling Sprinklers	12	12	4	4	6
Peak Gas Temperature at Ceiling Above Ignition (°F)	-	-	-	-	207
Maximum 1 Minute Average Gas Temperature at Ceiling Above Ignition (°F)	-	-	-	-	131
Peak Steel Temperature at Ceiling Above Ignition (°F)	169	117	113	113	102
Maximum 1 Minute Average Steel Temperature Above Ignition (°F)	559	266	291	112	100
Fire Spread Across Aisle	YES	YES	NO	NO	NO
Fire spread to the Ends of the Array	NO	NO	NO	NO	NO
Fuel Consumed (number of pallets)	12.5	5	2.5	0.5	25
Test Outcome (Pass/Fail)	FAIL	FAIL	PASS	PASS	PASS
Comments	Test failed due to 12 sprinklers activating	Test failed due to 12 sprinklers activating	Repeat of Test 2 with fan shutdown at waterflow	Repeat of Test 3A with 15 feet storage height	

FIRE TESTS	FPRF Test 5 (UL-2) 9/17/2010	FPRF Test 6 (UL-3) 9/21/2010	FPRF Test 7 (UL-4) 9/23/2010	FPRF Test 8 (UL-5) 9/28/2010	FPRF Test 9 (UL-6) 11/12/2010
PARAMETERS					
Location of Test	U.L.	U.L.	U.L.	U.L.	U.L.
Storage Type	Palletized Open Array	Palletized Open Array	Palletized Open Array	Palletized Open Array	Palletized Open Array
Commodity Type	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic
Nominal Storage Height (ft)	15	15	15	15	15
Nominal Ceiling Height (ft)	40	25	25	25	40
Nominal Clearance (ft)	25	10	10	10	25
Aisle Width (in.)	N/A	N/A	N/A	N/A	N/A
Longitudinal/Transverse Flue (in.)	12	12	12	12	12
Ignition Location	Between 4 Sprinklers (centered)	Between 4 Sprinklers (centered)	Between 4 Sprinklers (centered)	Between 4 Sprinklers (centered)	Between 4 Sprinklers (centered)
Igniter Details	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline
Sprinkler Type/Temperature Rating (°F)	ESFR/165	CMDA/286	CMDA/286	CMDA/286	ESFR/165
Sprinkler Orientation	Pendent	Upright	Upright	Upright	Pendent
Sprinkler Sensitivity	Fast Response	Std. Response	Std. Response	Std. Response	Fast Response
Sprinkler Make/Model Number	Tyco/ESFR-1	Tyco/ELO-231-B	Tyco/ELO-231-B	Tyco/ELO-231-B	Tyco/ESFR-1
Deflector to Ceiling (in.)	14	3	3	3	14
Nominal Sprinkler Discharge Coefficient K $(gpm/psi^{1/2})$	14	11.2	11.2	11.2	14
Density/Nominal Sprinkler Discharge Pressure (psi)	75	0.60 gpm/sq ft	0.60 gpm/sq ft	0.60 gpm/sq ft	75
Sprinkler Spacing (ft x ft)	10 x 10	8 x 10	8 x 10	8 x 10	10 x 10
Fan Size (ft)	24	24	24	24	24
Fan Location	Hub Above Ignition	Fan Tip 3 ft Beyond Ignition	Hub 1 ft West of Ignition	Fan Tip 3 ft Beyond Ignition	Fan Tip 2 ft Beyond Ignition
Fan Distance Below Ceiling (in.)	54.5	54.5	54.5	54.5	72
HVLS Fan Speed (rpm)	63	63	63	63	64
HVLS Fan Operation	On (no shutdown)	Off at Air Sampling-Type Detection (1:36) (no delay)	Off at Ion Smoke Detector Operation (1:43) (no delay)	Off at Waterflow (90 sec delay)	On (no shutdown)
HVLS Fan Manufacturer	MacroAir	MacroAir	MacroAir	MacroAir	Rite-Hite
HVLS Fan Model Name	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL	Revolution
HVLS Fan Model Number	MA24XL2006	MA24XL2006	MA24XL2006	MA24XL2006	-
HVLS Fan Blade Geometry	Whisperfoil XL	Whisperfoil XL	Whisperfoil XL	Whisperfoil XL	Propell-Aire Standard
HVLS Fan Number of Blades	6	6	6	6	4
RESULTS					
Length of Test (hr:min:s)	0:30:00	0:30:00	0:30:00	0:30:00	0:30:00
First Ceiling Sprinkler Operation (min:s)	1:05	1:36	2:08	1:13	0:56
Last Ceiling Sprinkler Operation (min:s)	1:57	1:58	3:28	3:01	1:51
Number of Operated Ceiling Sprinklers	6	6	7	20	8
Peak Gas Temperature at Ceiling Above Ignition (°F)	181	1468	504	1506	181
Maximum 1 Minute Average Gas Temperature at Ceiling Above Ignition (°F)	154	1042	360	1287	131
Peak Steel Temperature at Ceiling Above Ignition (°F)	118	244	122	415	121
Maximum 1 Minute Average Steel Temperature Above Ignition (°F)	105	219	122	410	116
Fire Spread Across Aisle	NO	NO	NO	NO	NO
Fire spread to the Ends of the Array	NO	NO	NO	NO	NO
Fuel Consumed (number of pallets)	23	26	15	32	28
Test Outcome (Pass/Fail)	PASS	PASS	PASS	PASS	PASS
Comments			Fan blades failed (bent) after shutdown		Repeat of Test 4 using different fan model

APPENDIX C – FM GLOBAL REPORT EXCERPTS

FM GLOBAL REPORT EXCERPTS

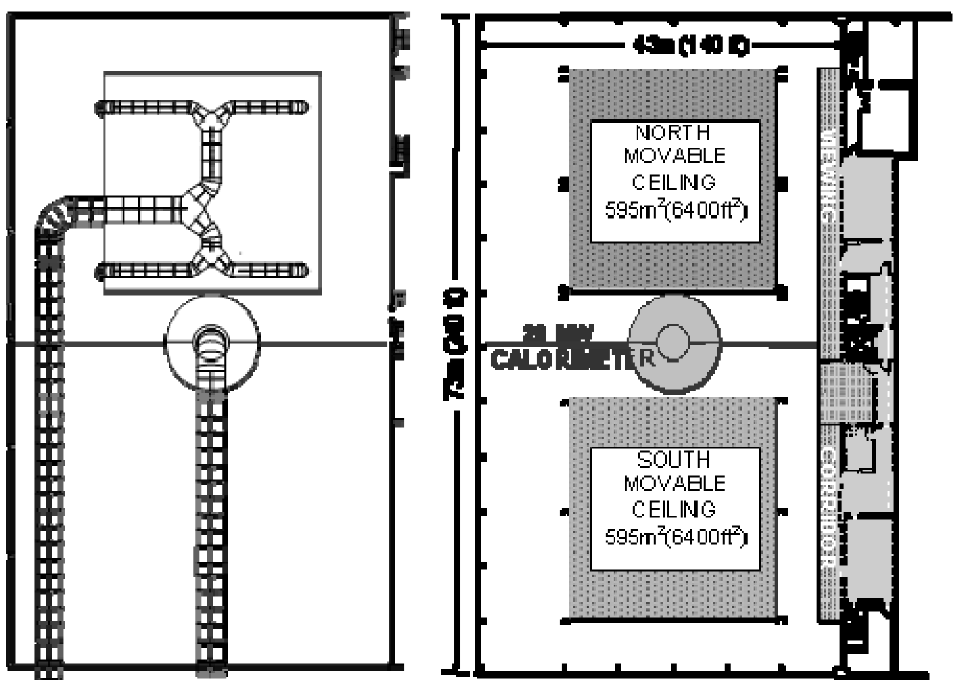
The following is a collection of excerpts from the FM Global research report. The reference for the report is:

Ditch, B. "Impact of a High Volume Low Speed Fan on Sprinkler Performance in Rack Storage Fire Tests," FM Global, Johnston, RI, 2010.

The full report will be published in its entirety and made available by FM Global on their website.

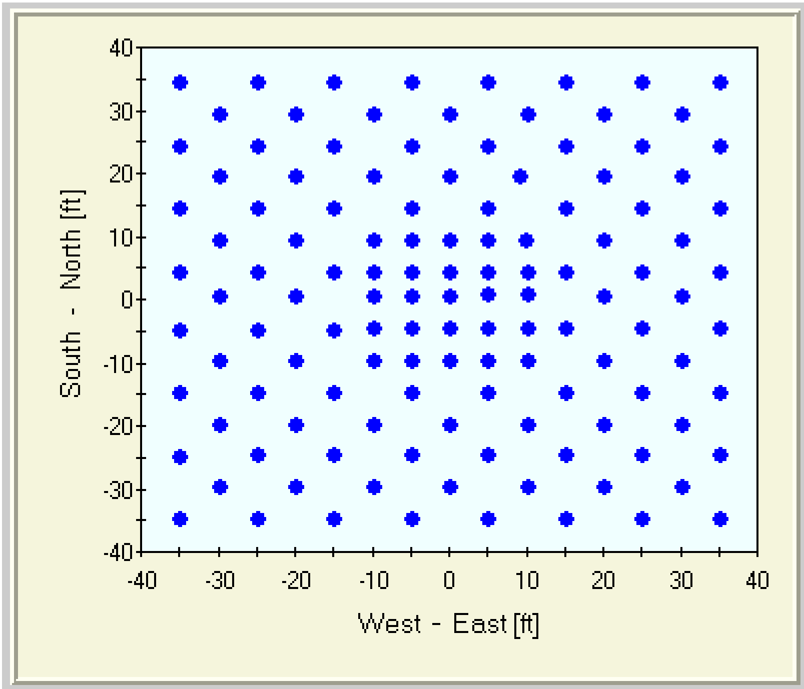
FM GLOBAL TEST FACILITY

The tests for this program were conducted under either the North or the South movable ceilings in the Large Burn Laboratory (LBL) located in the Fire Technology Laboratory at the FM Global Research Campus in West Glocester, Rhode Island. The below figure presents a plan view of the LBL showing the north movable ceiling, the south movable ceiling, and the 20-MW Calorimeter. The air emission control system (AECS) exhaust ducting shown above the north movable ceiling consists of four extraction points that merge into a single duct with a cross sectional area of 6.1 m2 (66 ft^2). A duplicate extraction system is present above the south ceiling, but is not shown in the figure. Gas concentration, velocity, temperature, and moisture measurements are made downstream of the manifold. Beyond the measurement location, the exhaust duct connects to a wet electrostatic precipitator (WESP) prior to the gases venting to the atmosphere. The movable ceilings measures 24.4 m x 24.4 m (80 ft x 80 ft) and are adjustable for heights above the floor ranging from 3.1 m (10 ft) to 18.3 m (60 ft). All tests were conducted at an exhaust rate of 5663 m3/min (200,000 ft^3/min).



INSTRUMENTATION

The ceiling is instrumented with bare-bead, 0.8 mm (20-gage), chromel-alumel thermocouples, placed 165 mm (6-1/2 in) below the ceiling at 125 locations. These thermocouples have been shown to have a response time index (RTI) of 8±1 $m^{1/2}s^{1/2}$ (14.5±1.8 $ft^{1/2}s^{1/2}$).



IGNITER DETAILS

Ignition was achieved with two FM Global standard half igniters, which are 76 mm x 76 mm (3 in x 3 in) cylinders of rolled cellu-cotton. Each igniter is soaked in 118 ml (4 oz) of gasoline and sealed in a plastic bag. The igniters were placed in an offset ignition orientation, which is located 0.6 m (2 ft) east of center, in the center transverse flue, between the uprights, of the eastern row of the main array. The igniters were lit with a flaming propane torch at the start of each test and the fires were allowed to develop naturally.

TEST RESULTS AND DATA ANALYSIS

This section contains the results of the four large-scale fire tests conducted to evaluate the effect of an High Volume/Low Speed (HVLS) fan on the protection provided by a ceiling level sprinkler system. A summary of the test conditions and results is shown in Table 1.

Table **Error! No text of specified style in document.**1: Summary of test setup and results:

Configuration and Results	Test 1	Test 2	Test 3	Test 4
Detailed Analysis, Appendix	B	C	D	E
Test Configuration				
Commodity	Cartoned Unexpanded Plastic (CUP), Double Row Rack Storage			
Commodity / Ceiling Height [m (ft)]	9.1 / 12.2 (30 / 40)	9.1 / 12.2 (30 / 40)	9.1 / 12.2 (30 / 40)	4.6 / 12.2 (15 / 40)
Main Array Located Below – number of sprinklers	1	4	4	4
Fan Operation	Full speed, Entire test		Full speed, Off at 90s	
Test Results				
Sprinklers Operations	12	12	4	4
Total Energy† [MJ (BTU x 103)]	18,000 ± 2000 (17,000 ± 3,400)	7,500 ± 1,100 (7,100 ± 1,000)	3,500 ± 500 (3,300 ± 500)	750 ± 100 (700 ± 100)
Consumed Commodity [pallet load equivalent]	12.5	5	2.5	0.5
Target Jump (east/west) @ Time [min:s]	East, 3:09 West, 5:50	East, 2:13 West, no	East, 3:00 West, no	East, no West, no
Maximum One-Minute Steel Temperature [oC (oF)]	76 (169) @ 5:54	47 (117) @ 4:49	45 (113) @ 4:41	28 (113) @ 1:46
Maximum One-Minute TC Measurement [oC (oF)]	293 (559) @ 4:26	120 (266) @ 3:07	144 (291) @ 1:45	44 (112) @ 1:42
Test Termination [min:s]	35:00	25:00	30:00	30:00

† To allow for a meaningful comparison of total energy generated, tests were conducted until the fire was largely extinguished (only minimal lingering fire remained) by the sprinkler system.

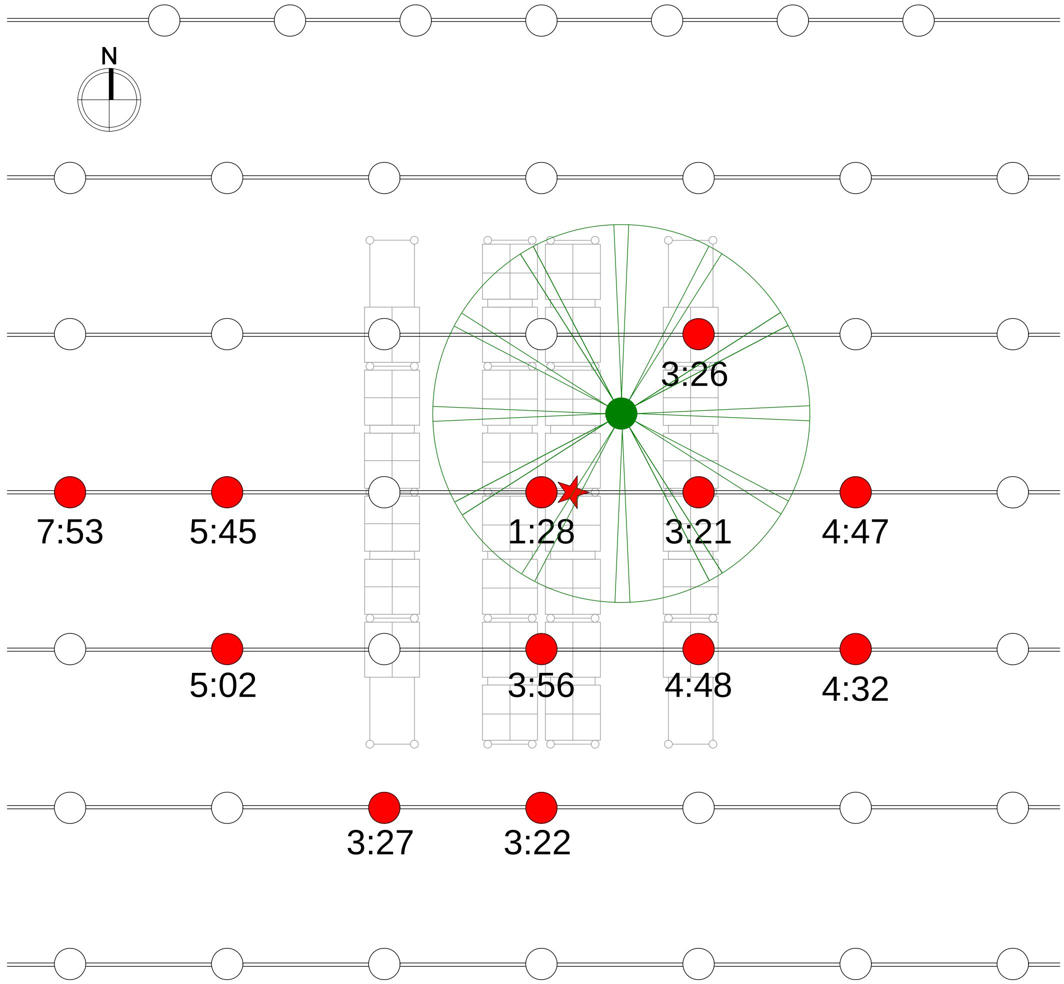
Protection for each test was provided by quick-response, pendent sprinklers, having a 70°C (165°F) rated link and a K-factor of 161 L/min/bar$^{1/2}$ (14 gpm/psi$^{1/2}$). Sprinklers were installed on 3.0 x 3.0 m (10 x 10 ft) spacing to provide a 48.9 mm/min (1.2 gpm/ft^2) density over the protected area. The ceiling was set to a height of 12.2 m (40 ft) above the floor.

Tests 1 and 2 were conducted to evaluate the HVLS fan location resulting in the greatest negative impact on sprinkler system performance. For Test 1, the main array was centered below one sprinkler and the fan was offset 2.2 m (7.1 ft) to the northeast. A total of 12 sprinklers operated with the first operation occurring at 1 min 28 s after ignition. Fire spread remained within the confines of test arrays; however, extensive damage occurred on both the east and west rows of the main array and the aisle face of both the east and west target arrays. For Test 2, the main array was centered among four sprinklers and the fan was centered[1] over the main array. A total of 12 sprinklers operated with the first operation occurring at 1 min 42 s after ignition. Fire spread remained within the confines of the main array with damage primarily sustained on the eastern row; however, there was extensive damage to the commodity on the backside of the east target array. Both tests exceeded the evaluation criterion for the allowable number sprinkler operations. Test 2 additionally exceeded the extent of damage criterion and was considered the worst-case configuration.

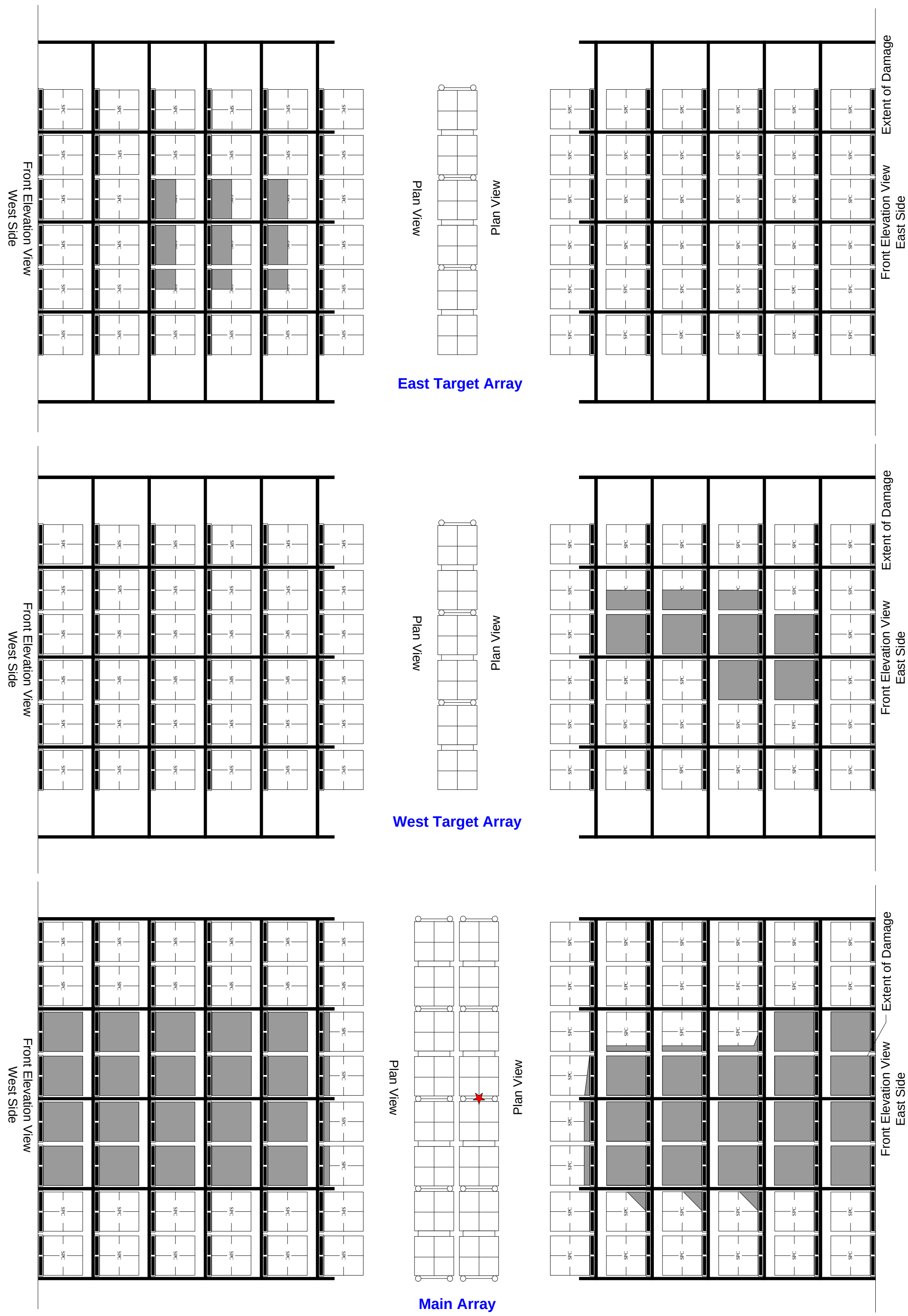
[1] The actual fan placement was offset 0.3 m (1 ft) northeast of the ceiling center due to the presence of the instrumentation used to acquire ceiling steel temperatures.

Test 3 was conducted to evaluate the effect of shutting the fan down due to a water flow alarm. The configuration was identical to Test 2, except the fan was shut off 1 min 30 s after first sprinkler operation. A total of 4 sprinklers operated with the first operation occurring at 1 min 54 s after ignition. Fire spread remained within the confines of the main array with damage primarily sustained on the eastern row and minimal damage to the commodity on the aisle face of the east target array. These results are within the specified levels and indicate that fan shut down due to a water flow alarm can allow sprinkler system to perform acceptably.

Test 4 was conducted to evaluate the effect of a high clearance between the top of the stored commodity and the ceiling. The general test configuration was consistent with Tests 2 and 3, except a lower storage height of 4.6 m (15 ft) resulted in a 7.6 m (25 ft) clearance. The fan was shut off 1 min 30 s after first sprinkler operation.

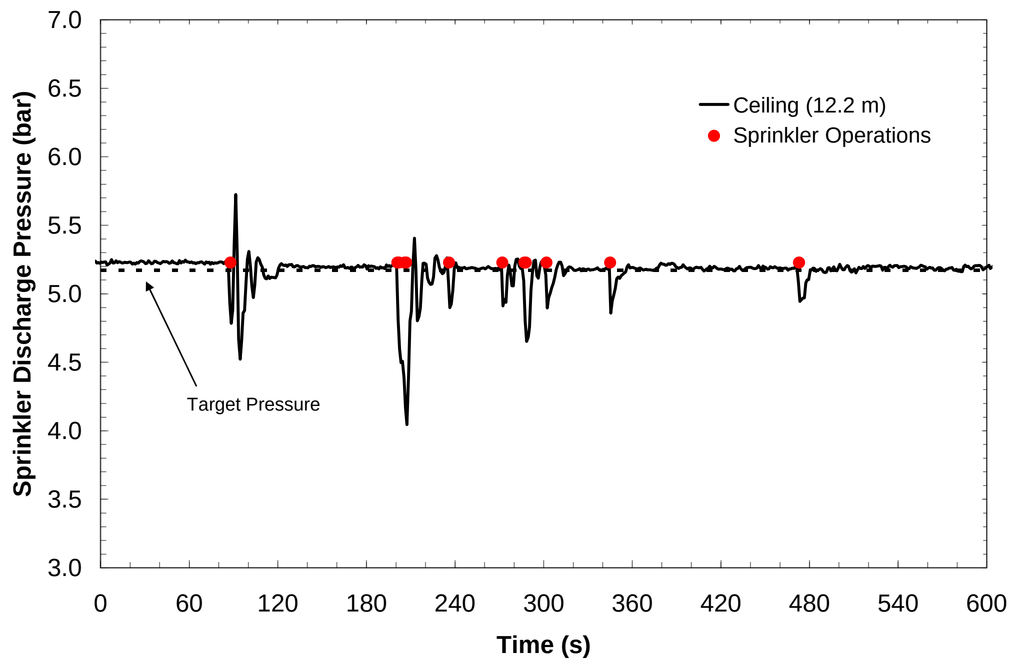


<u>3038945 Test #1</u>
40' ceiling / 30 Commodity
Tyco ESFR-1 Pendent K14 @ 75 psi = 1.2 gpm/ft^2
Arrayed centered under-1, Ignition offset 2-ft east
10' sprinkler x 10' pipe, 4-ft aisle
HVLS Fan 7.1 ft NE, 66 rpm, 24 ft diameter

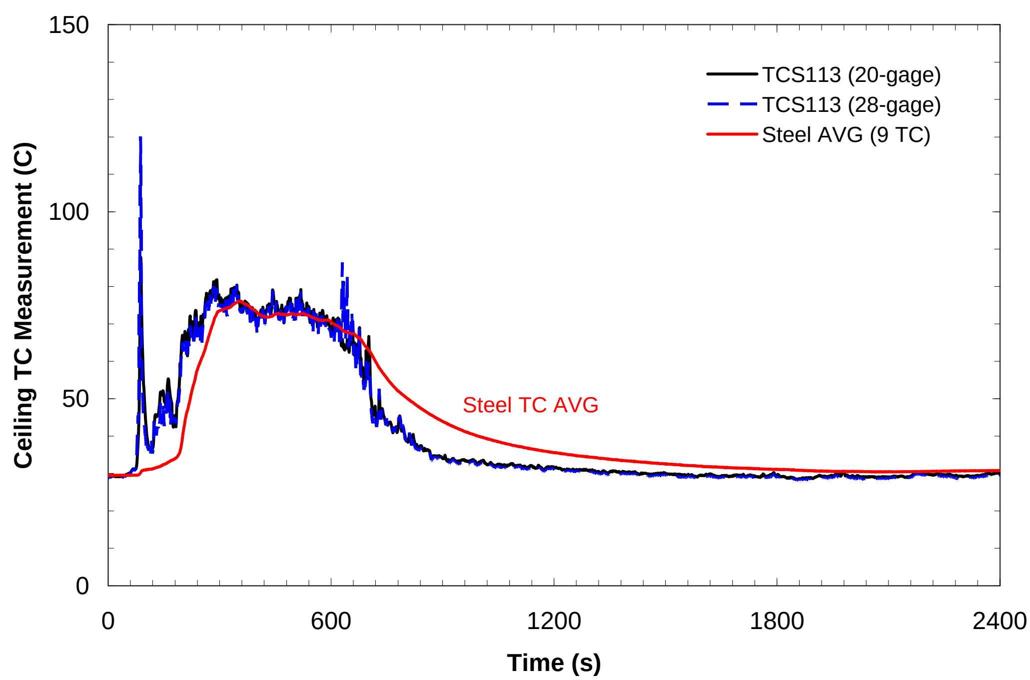


Damage to Commodity (Equivalent of 10 pallets loads consumed)

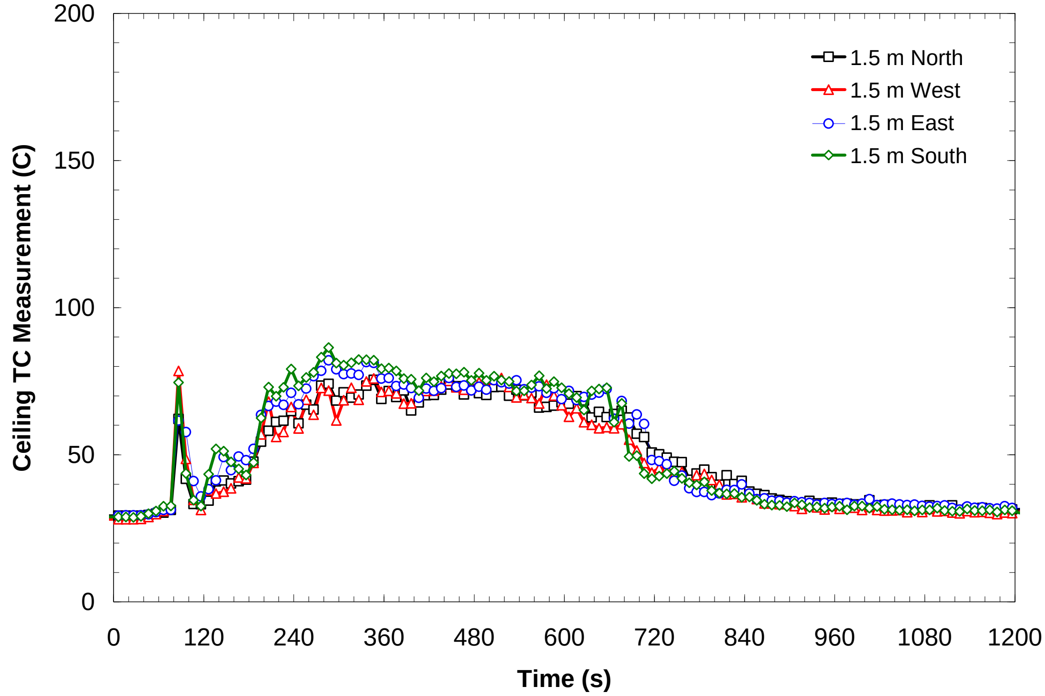
*Note that grey areas indicate at least superficial burning of commodity



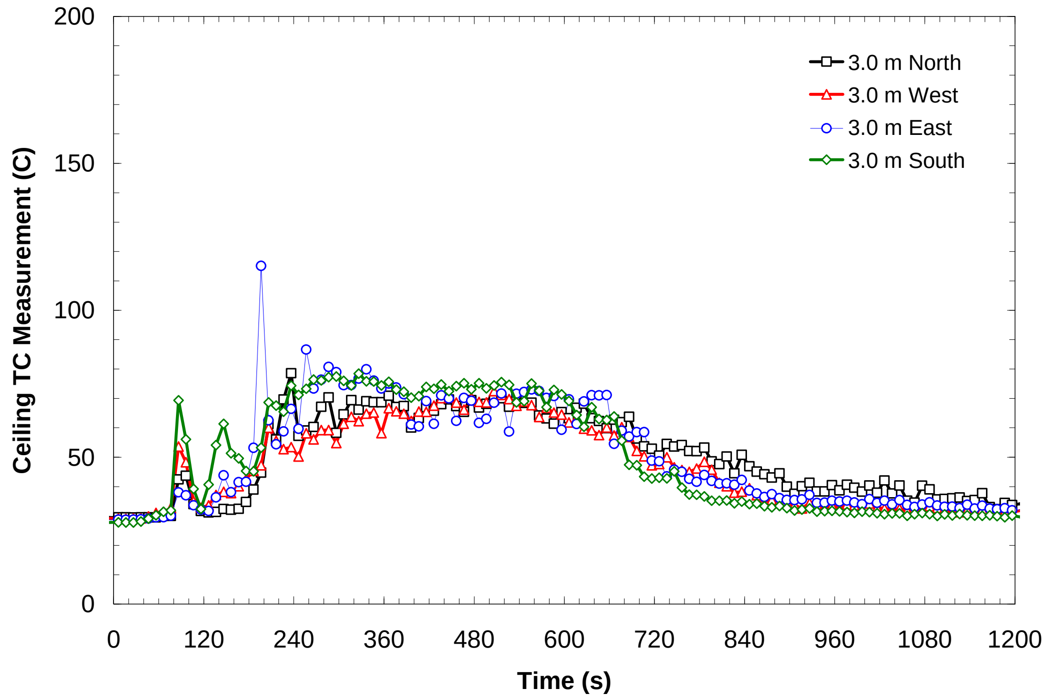
Sprinkler System Discharge Pressure



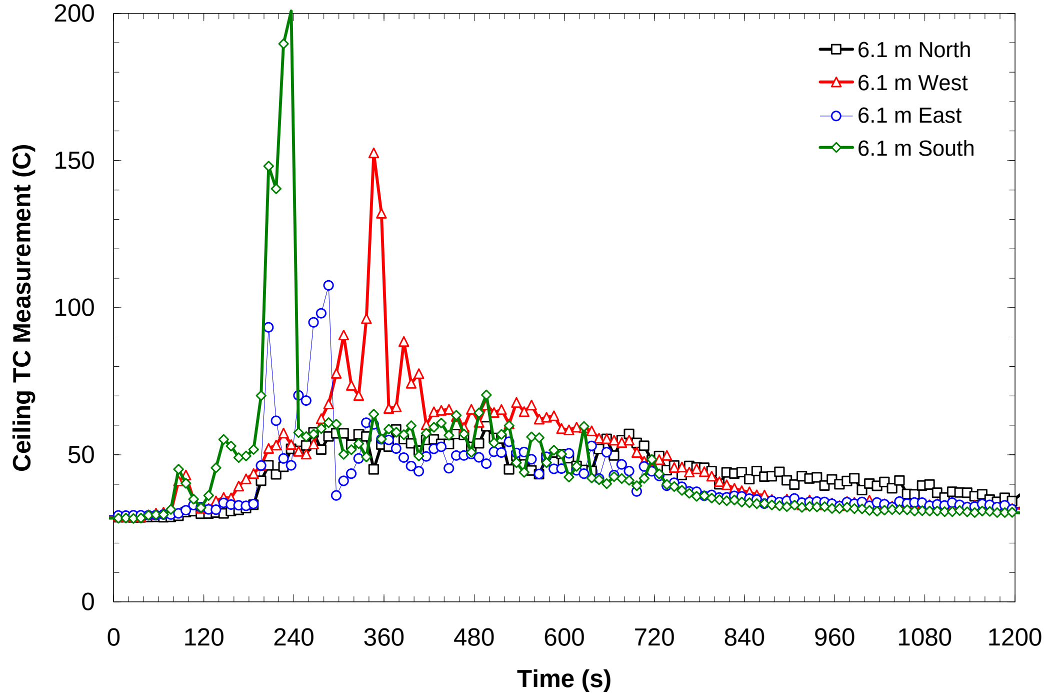
Ceiling TC Measurement Centered over Main Array and Steel TC Measurements



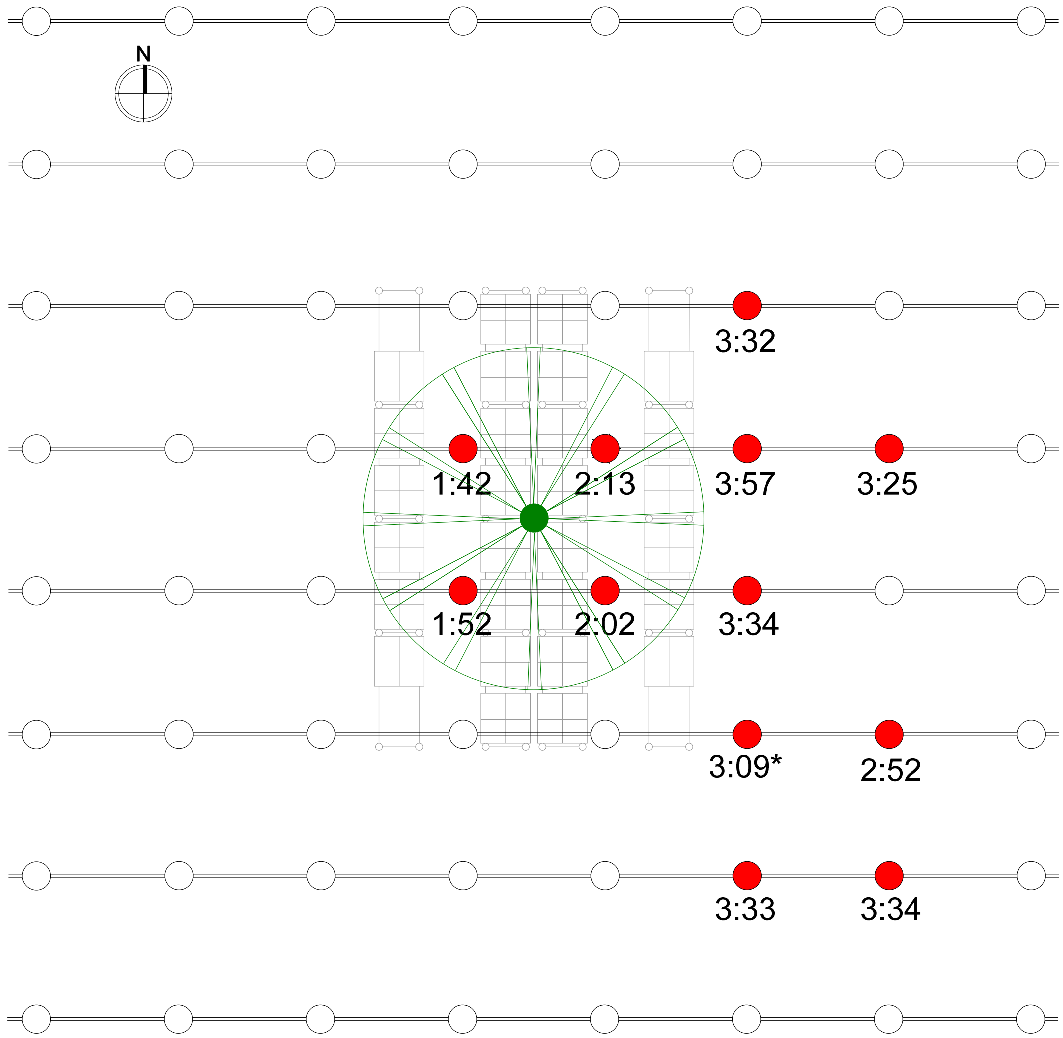
Ceiling TC Measurements 1.5 Radially from Ceiling Center



Ceiling TC Measurements 3.0 Radially from Ceiling Center

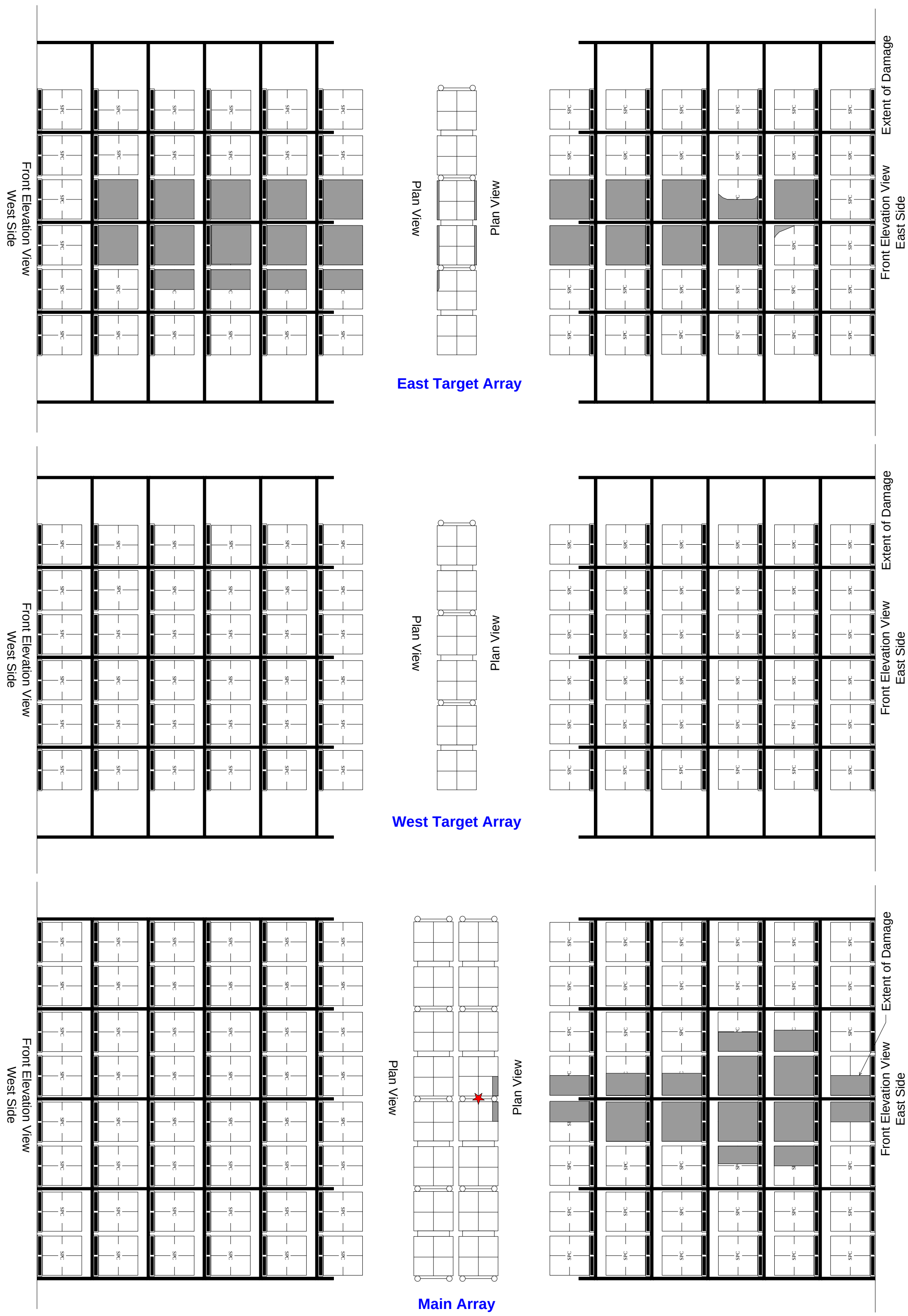


Ceiling TC Measurements 6.1 m Radially from Ceiling Center



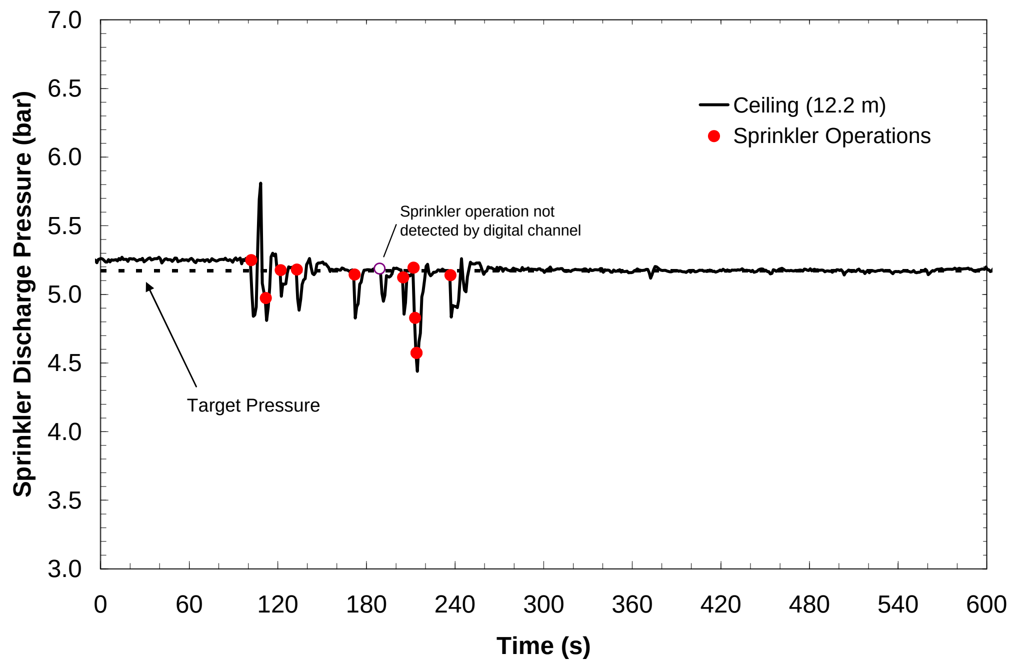
3038945 Test #2
40' ceiling / 30 Commodity
Tyco ESFR-1 Pendent K14 @ 75 psi = 1.2 gpm/ft^2
Arrayed centered among-4, Ignition offset 2-ft east
10' sprinkler x 10' pipe, 4-ft aisle
HVLS Fan Center over main array, 66 rpm, 24 ft diameter

*operation not identified by digital channel

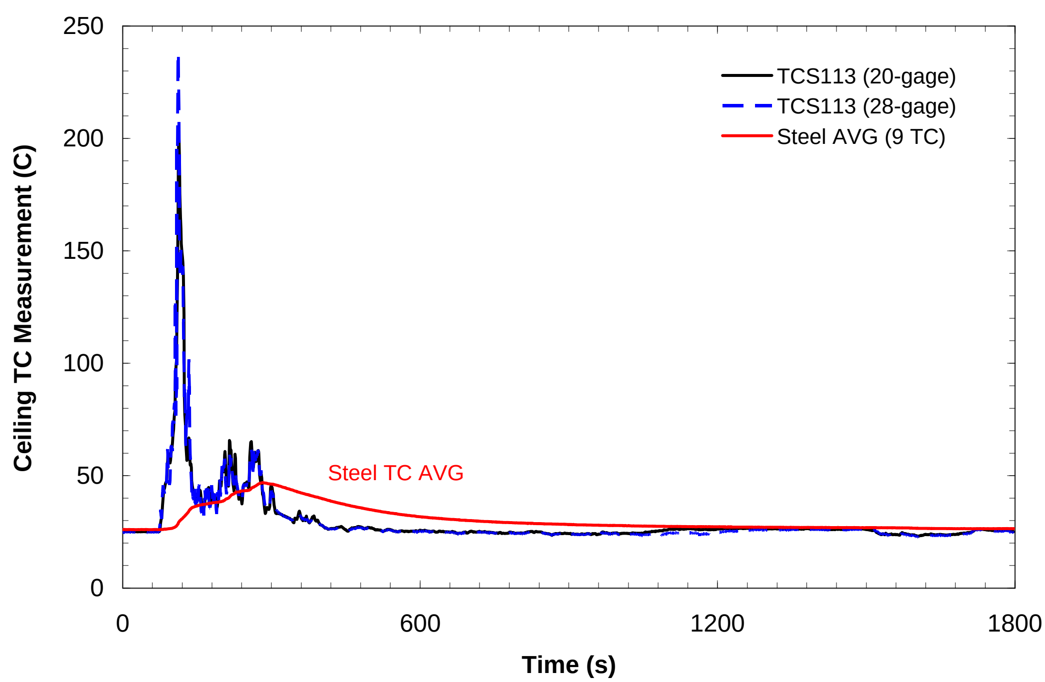


Damage to Commodity (Equivalent of 4.5 pallets loads consumed)

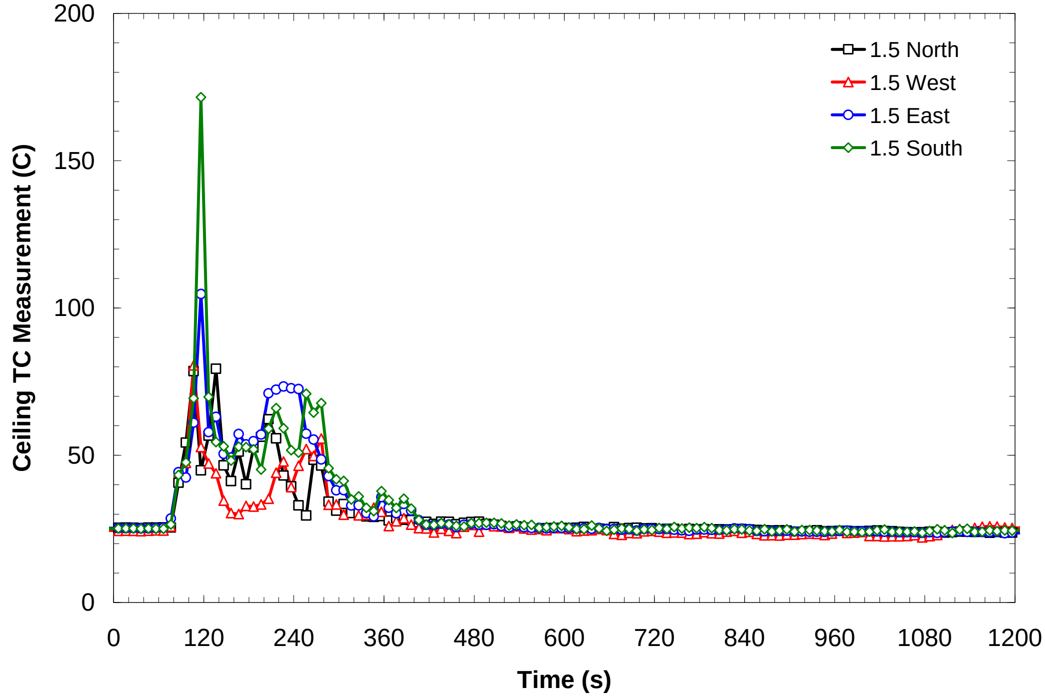
*Note that grey areas indicate at least superficial burning of commodity



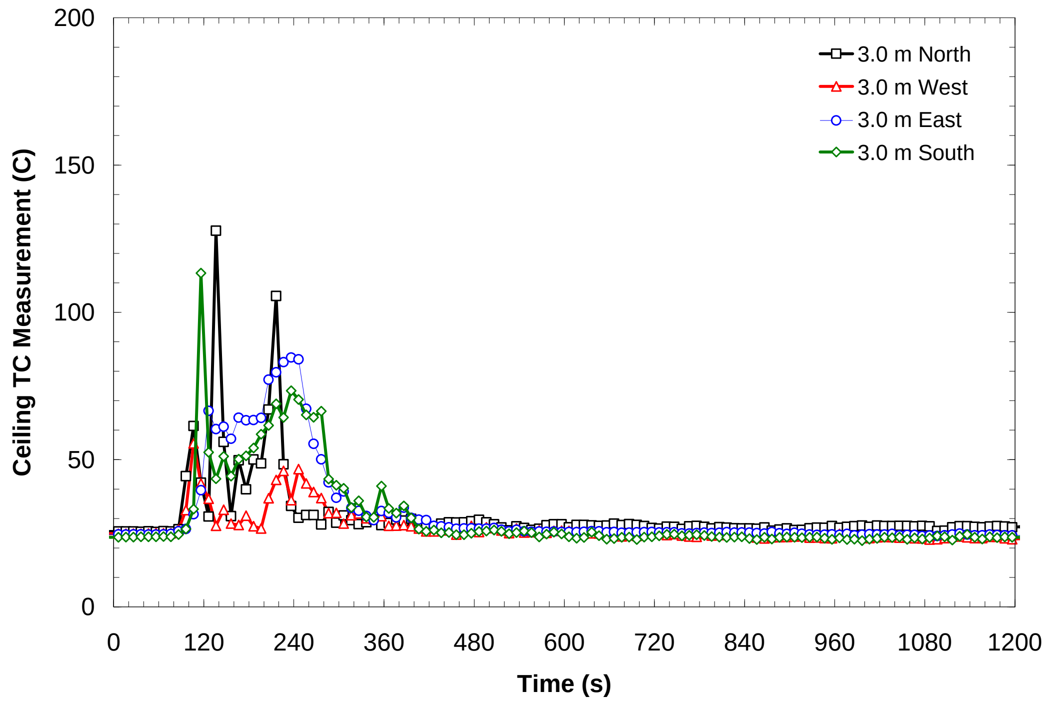
Sprinkler System Discharge Pressure



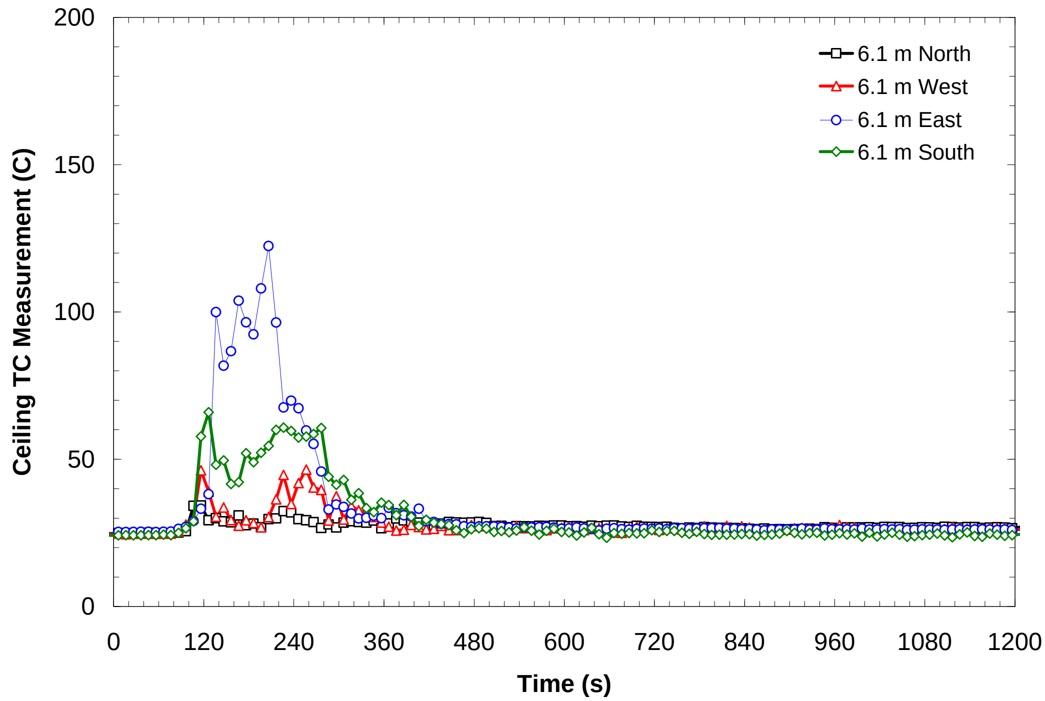
Ceiling TC Measurement Centered over Main Array and Steel TC Measurements



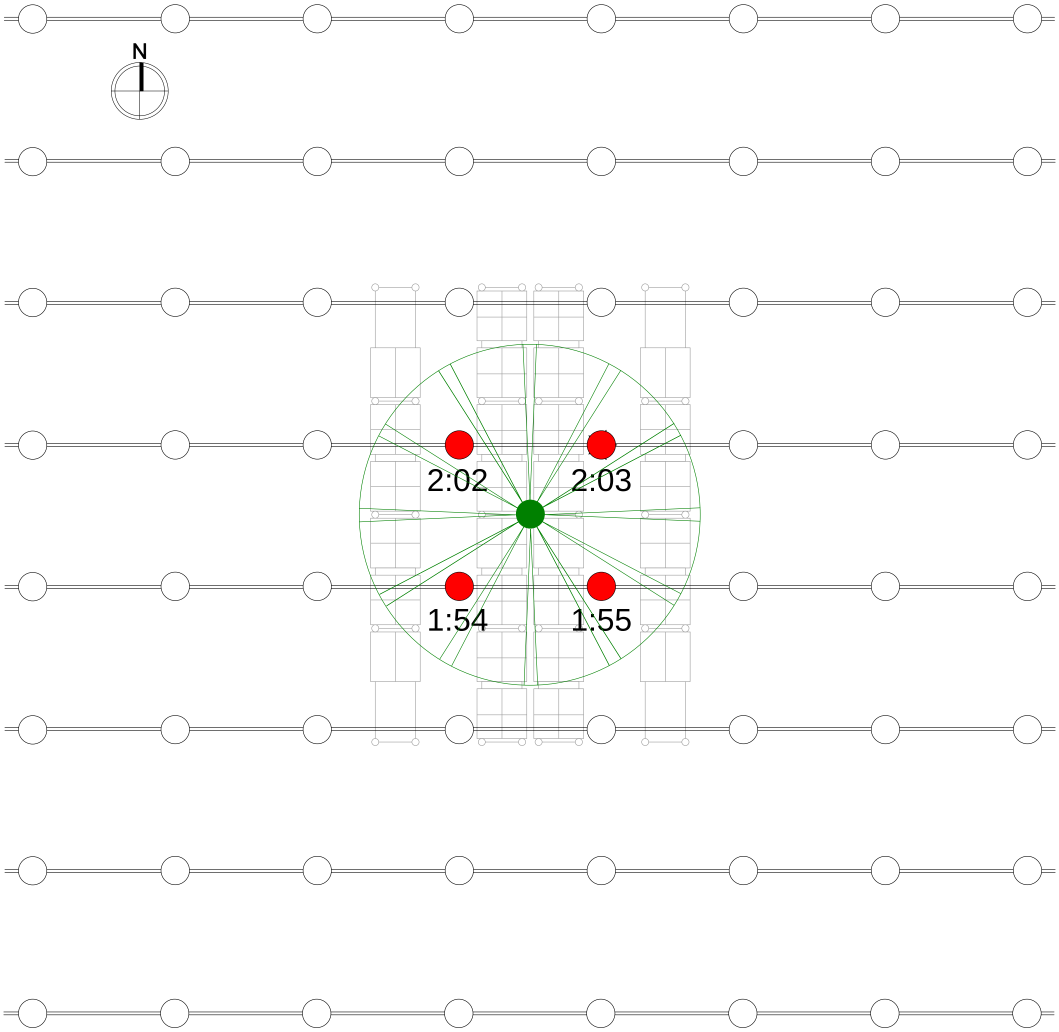
Ceiling TC Measurements 1.5 Radially from Ceiling Center



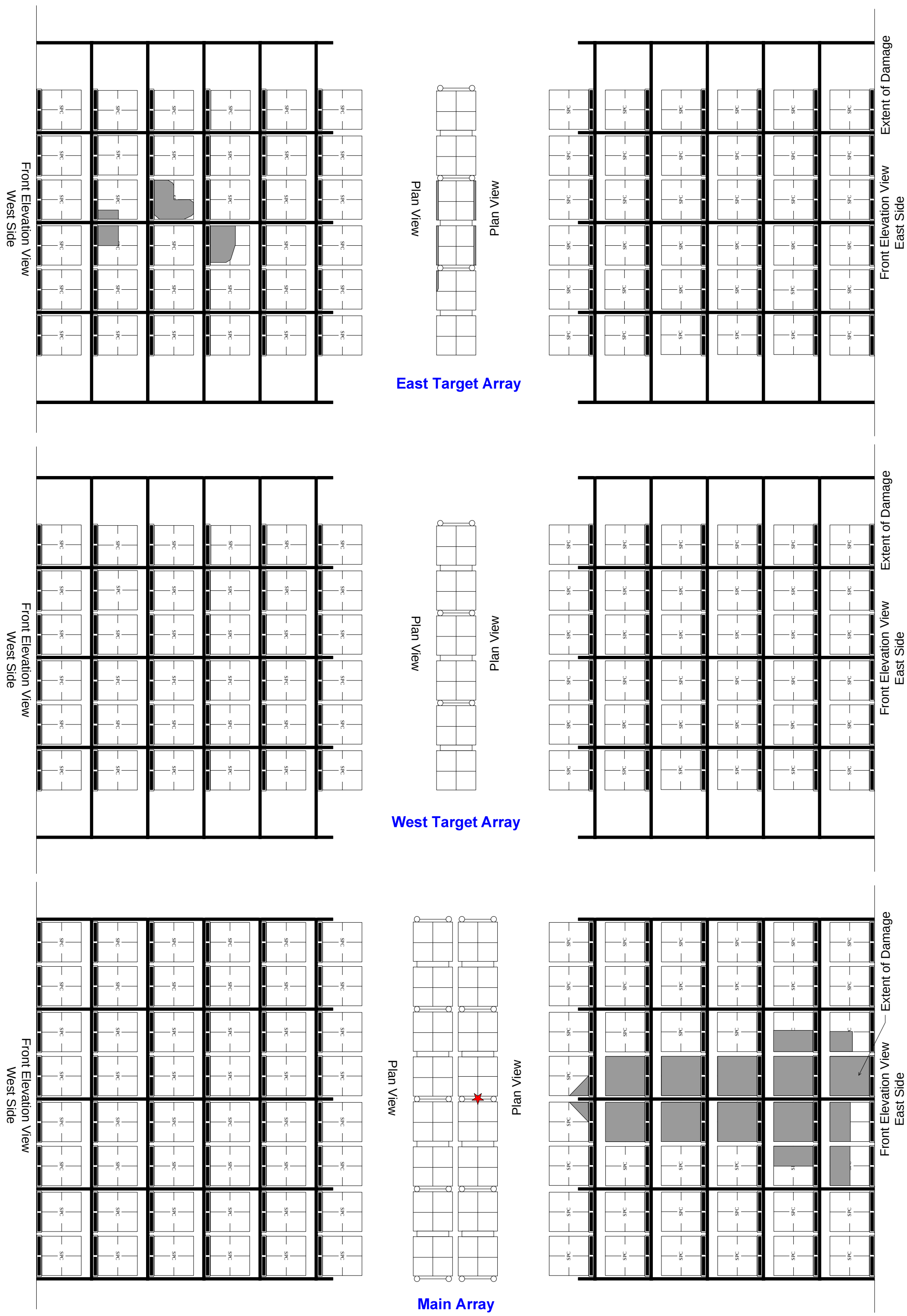
Ceiling TC Measurements 3.0 Radially from Ceiling Center



Ceiling TC Measurements 6.1 Radially from Ceiling Center

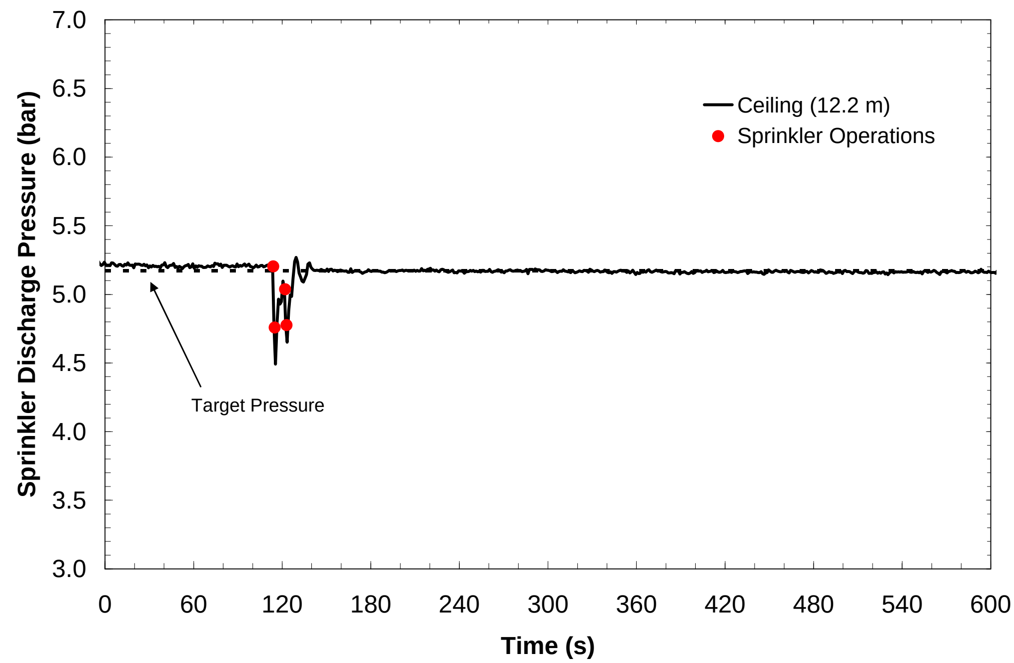


3038945 Test #3
40' ceiling / 30 Commodity
Tyco ESFR-1 Pendent K14 @ 75 psi = 1.2 gpm/ft^2
Arrayed centered among-4, Ignition offset 2-ft east
10' sprinkler x 10' pipe, 4-ft aisle
HVLS Fan Center over main array, 66 rpm, 24 ft diameter
Fan shut off 90 s after 1st sprinkler operation

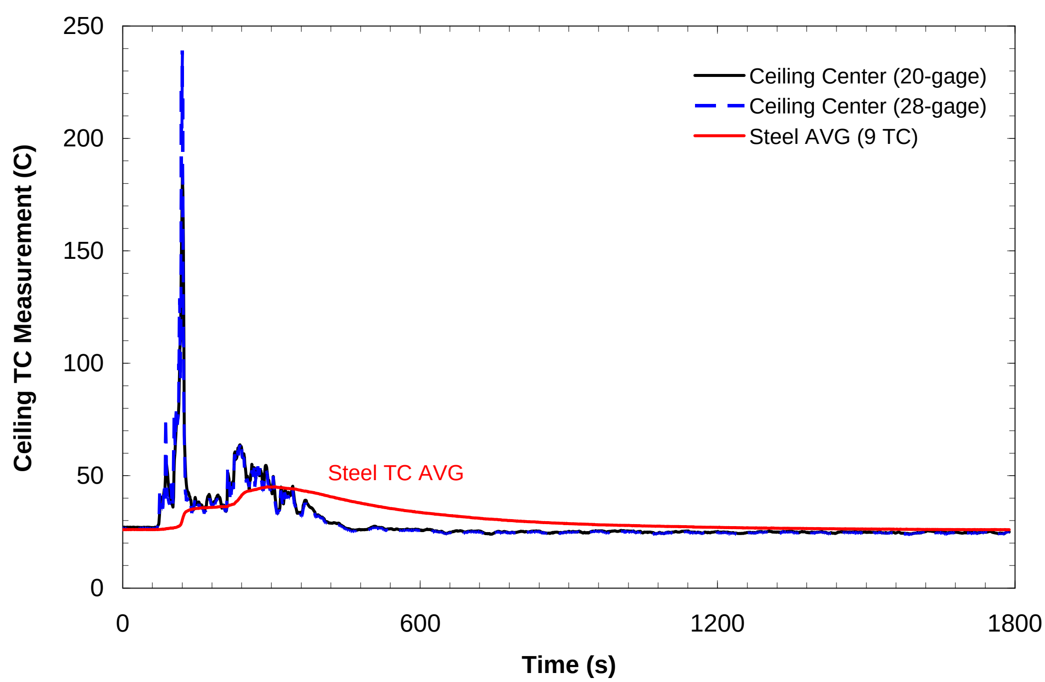


Damage to Commodity (Equivalent of 2.1 pallets loads consumed)

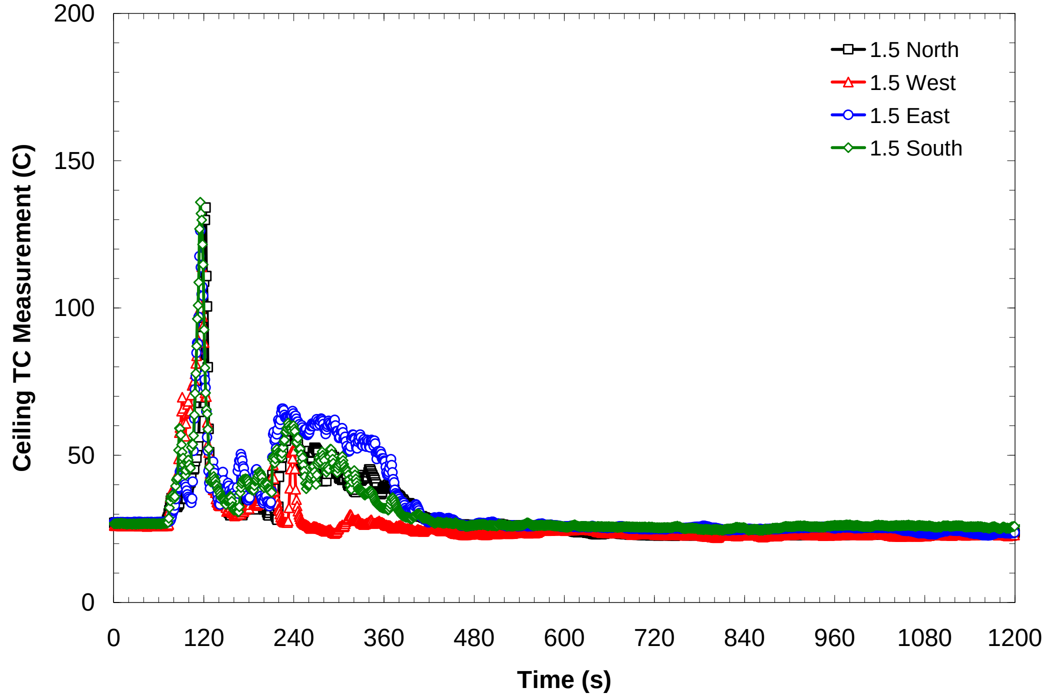
*Note that grey areas indicate at least superficial burning of commodity



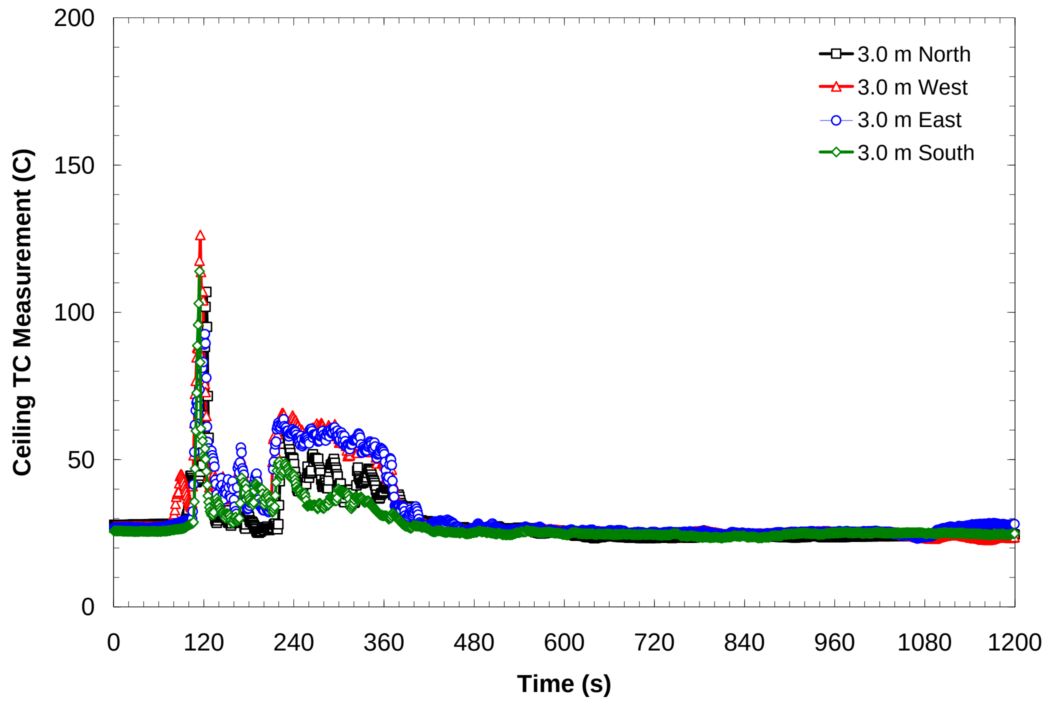
Sprinkler System Discharge Pressure



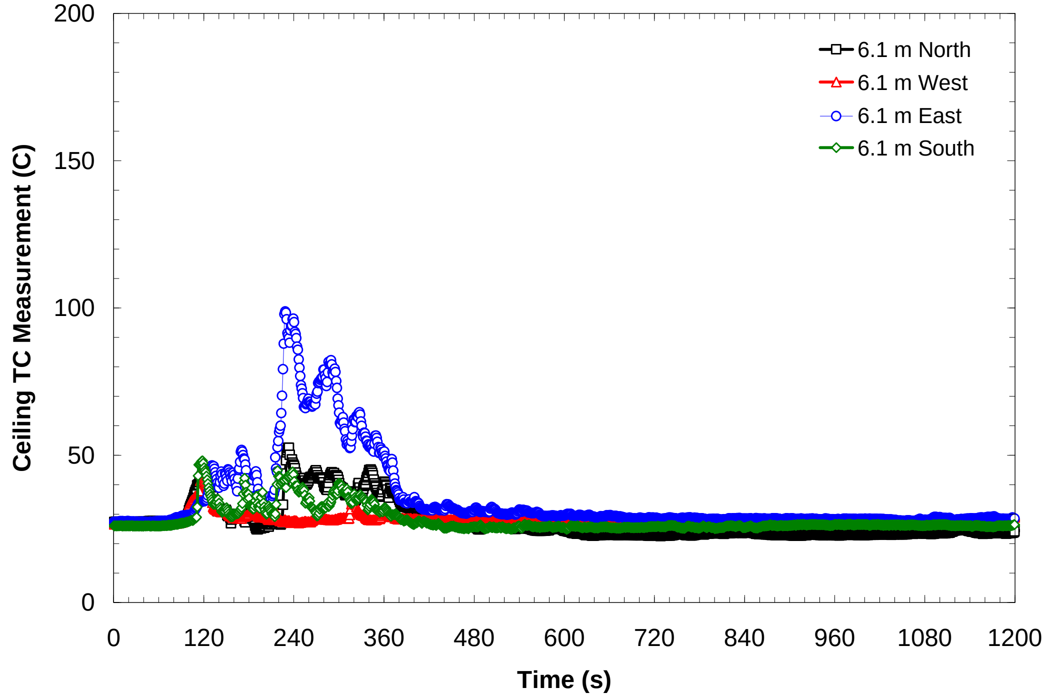
Ceiling TC Measurement Centered over Main Array and Steel TC Measurements



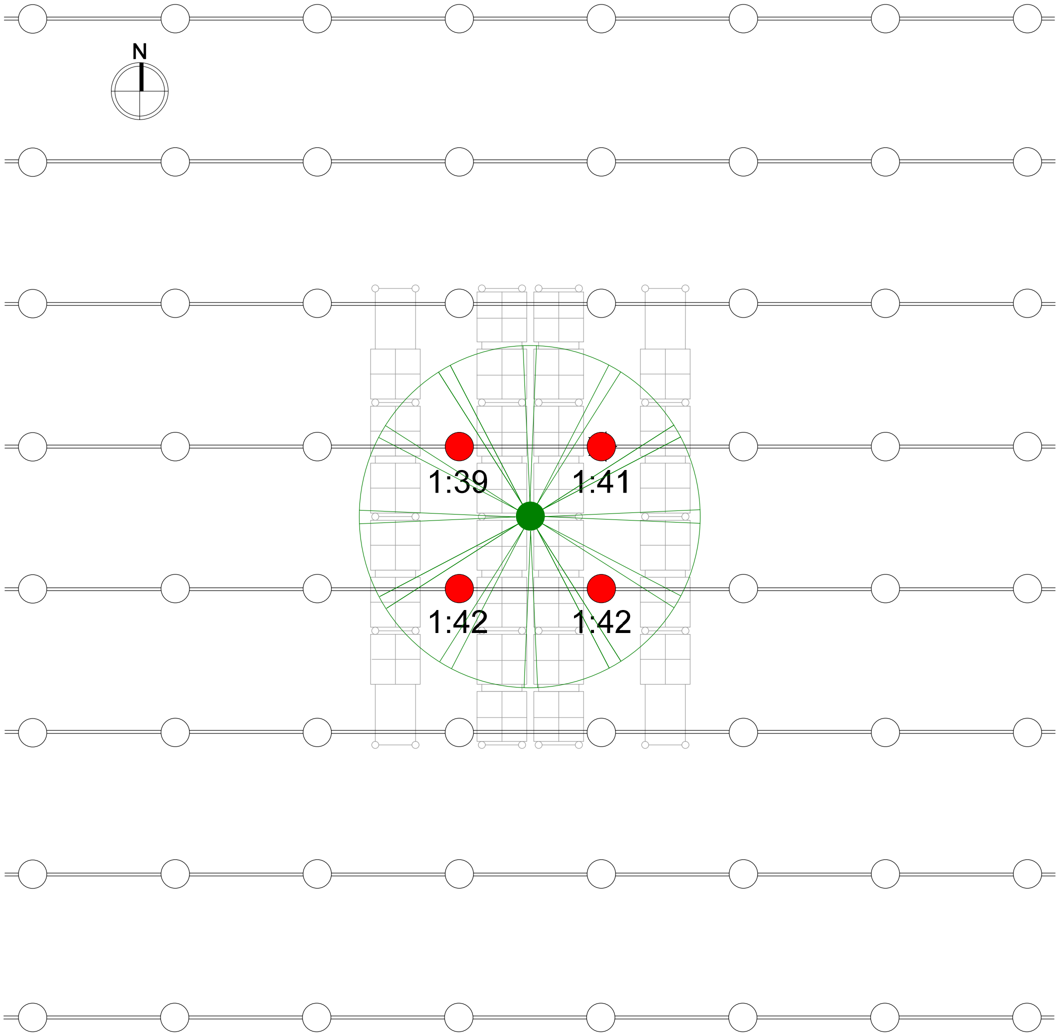
Ceiling TC Measurements 1.5 Radially from Ceiling Center



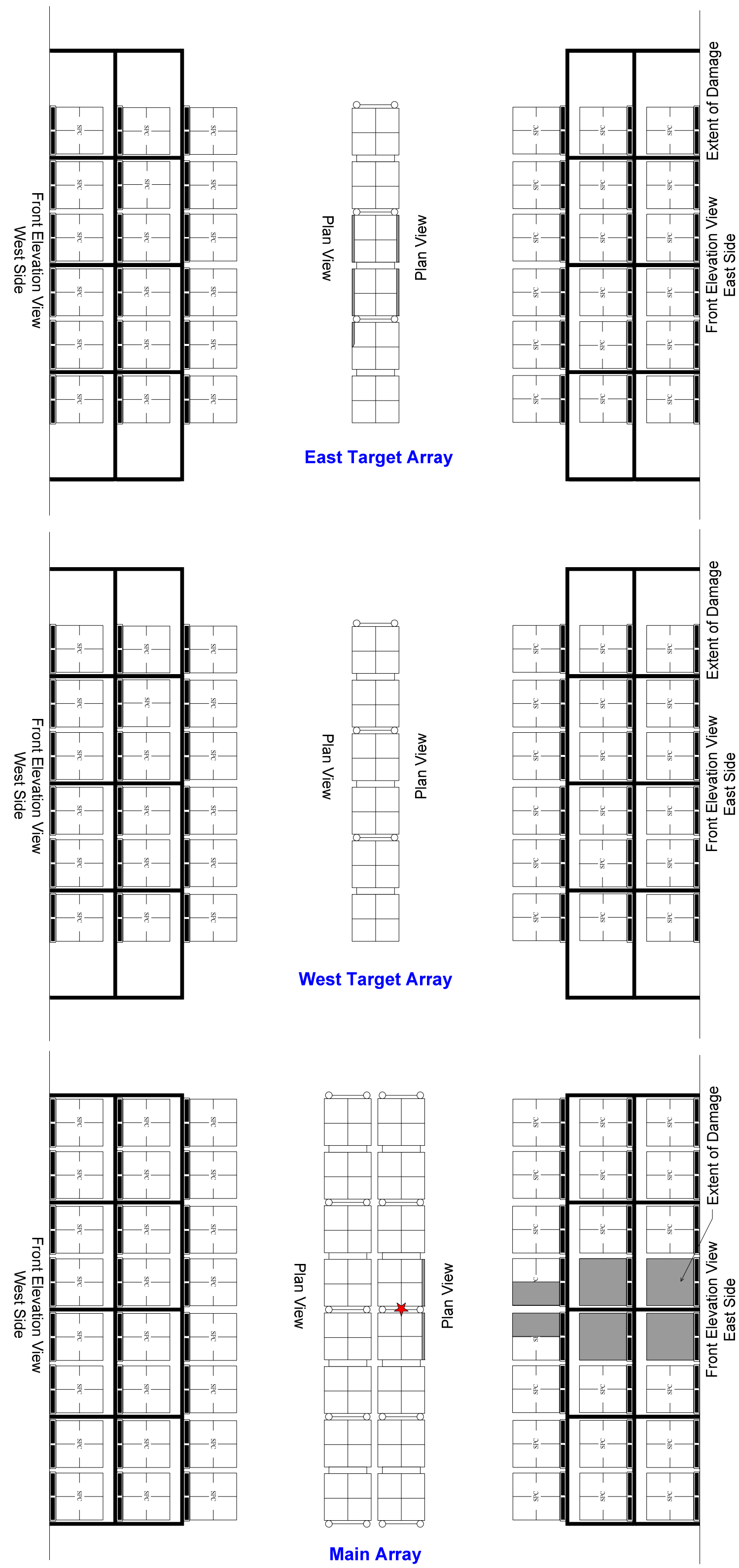
Ceiling TC Measurements 3.0 Radially from Ceiling Center



Ceiling TC Measurements 6.1 Radially from Ceiling Center

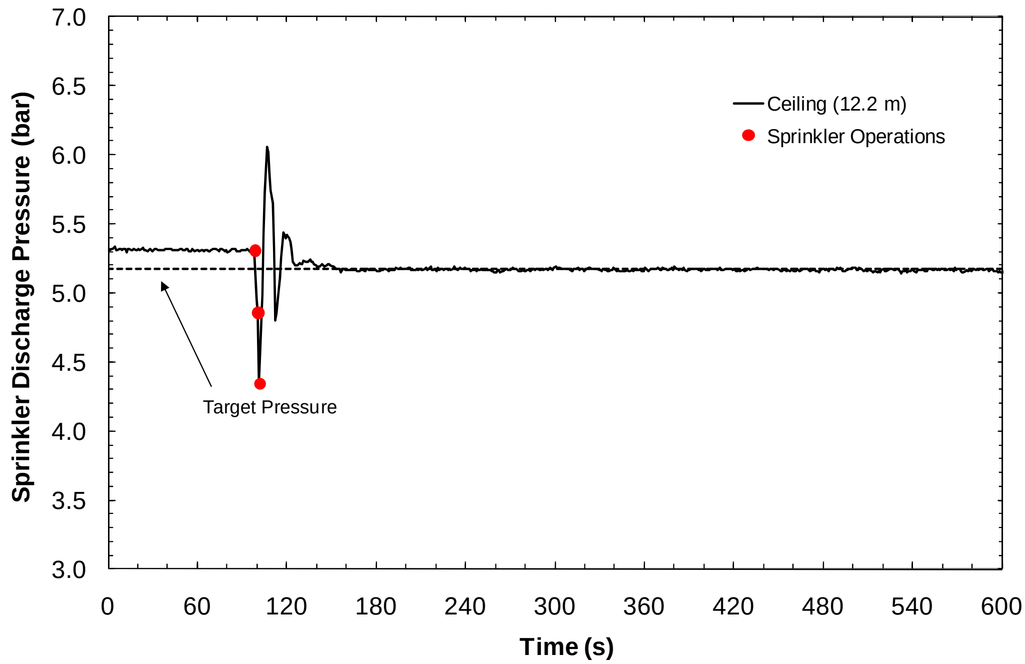


3038945 Test #4
40' ceiling / 15' Commodity
Tyco ESFR-1 Pendent K14 @ 75 psi = 1.2 gpm/ft^2
Arrayed centered among-4, Ignition offset 2-ft east
10' sprinkler x 10' pipe, 4-ft aisle
HVLS Fan Center over main array, 66 rpm, 24 ft diameter
Fan shut off 90 s after 1st sprinkler operation

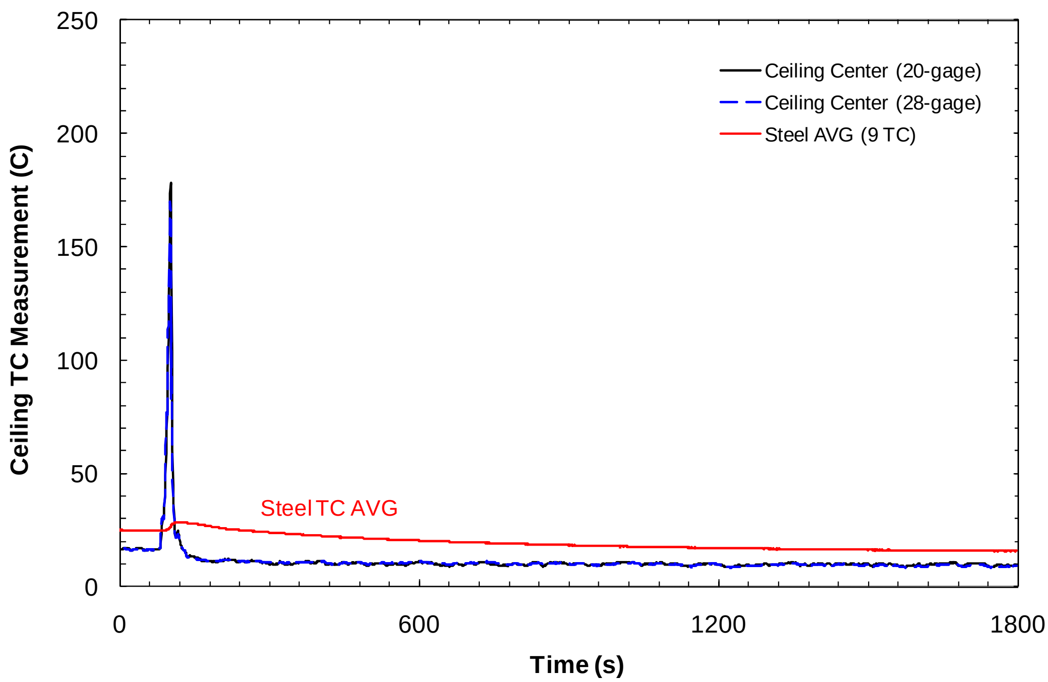


Damage to Commodity (Equivalent of 0.5 pallets loads consumed)

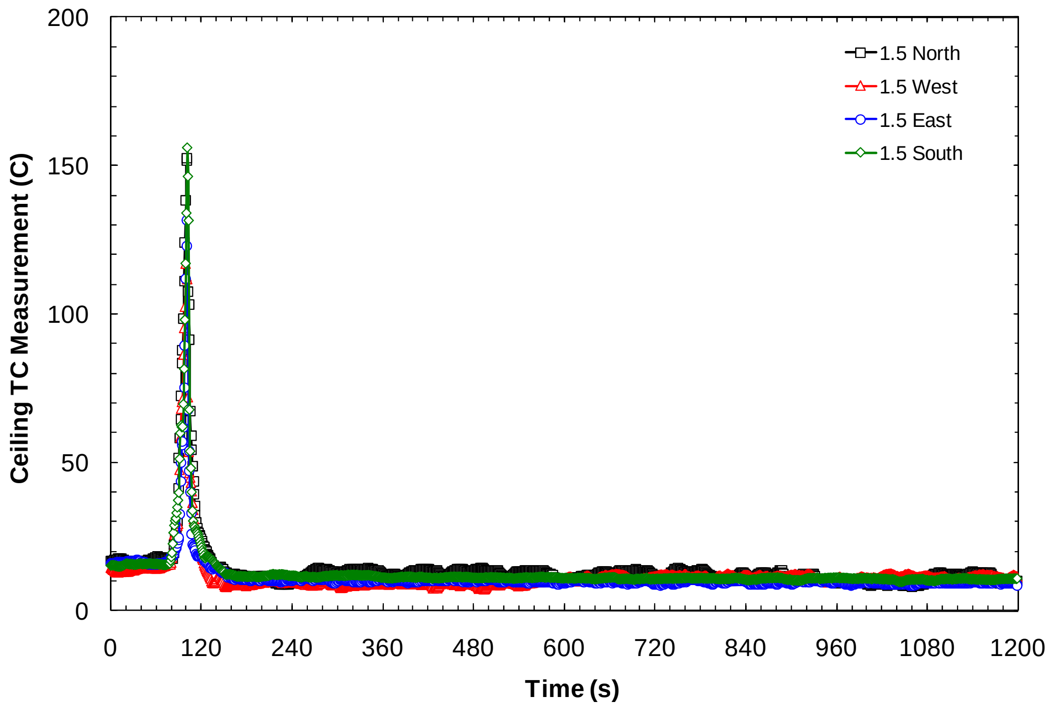
*Note that grey areas indicate at least superficial burning of commodity



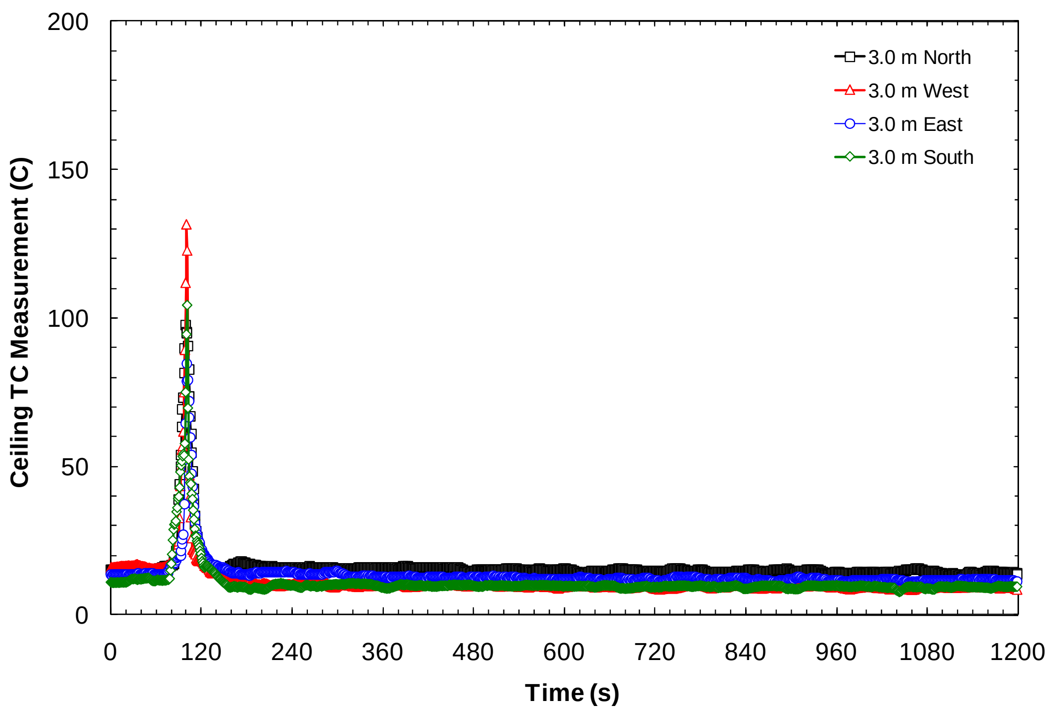
Sprinkler System Discharge Pressure



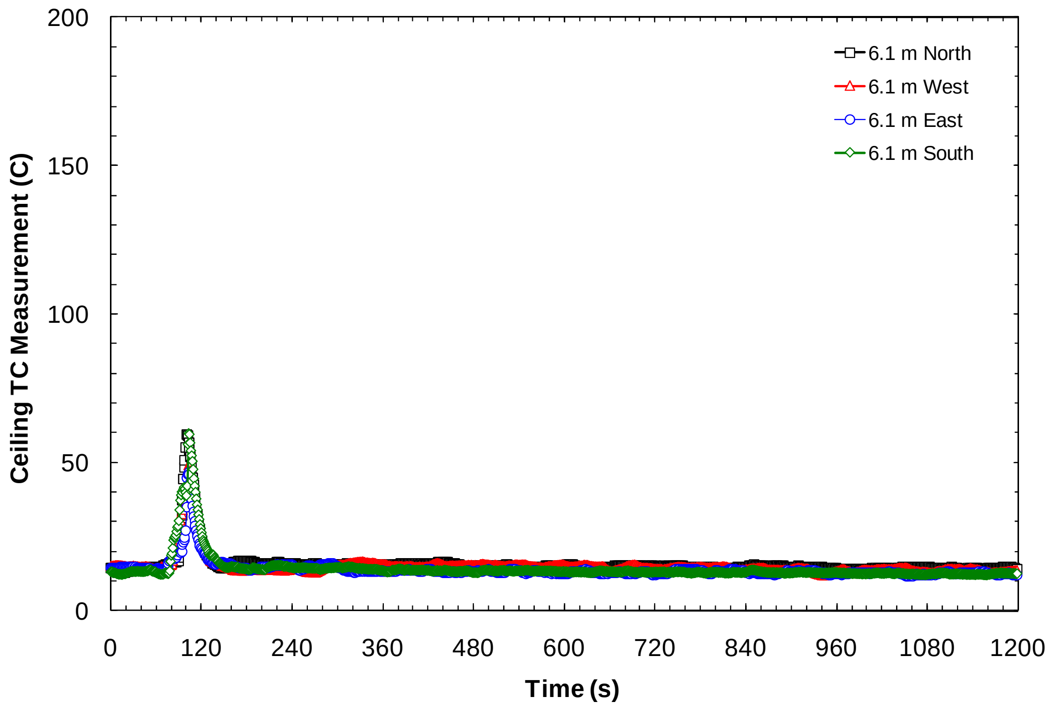
Ceiling TC Measurement Centered over Main Array and Steel TC Measurements



Ceiling TC Measurements 1.5 Radially from Ceiling Center



Ceiling TC Measurements 3.0 Radially from Ceiling Center



Ceiling TC Measurements 6.1 Radially from Ceiling Center

COLD FLOW AIR VELOCITY DATA

Table 1 presents the average air velocities measured at 15.2 cm (6 in) above the top of the main array for Tests 1 through 4. Air velocities were measured continually at 15 locations that were 12.7 cm (5 in) above the top of the main array, surrounding the ignition bay. The measurement locations were separated into three groups: W1 – W5 were 7.6 cm (3 in) out from the main array commodity in the west aisle, C1 – C5 were centered within the longitudinal flue, and E1 – E5 were 7.6 cm (3 in) out from the main array commodity in the east aisle.

Figures 1-4 illustrate the data present in Table 1. A plan view schematic of the measurement locations relative to the array and the fan was included for reference. As shown, positive values indicate upward flow and negative values indicate downward flow. Each value represents an average value over a minimum 30 minute duration and were acquired with only the fan operating, i.e., no fire or exhaust air. These are referred to as ‘cold flow’ measurements in this report.

For Test 1, where the fan was offset from the array center, the peak downward velocity exceeded 4.5 m/s (14.8 ft/s). Consistent with typical fan air flow, the higher velocities were generally experienced around 50% of the fan blade length. This resulted in higher velocities in the eastern aisle spaces than the western aisle space. For the array configuration used in Tests 2 and 3, where the fan was centered over the array, the peak downward velocity decreased to 3.5 m/s (11.5 ft/s) and was more evenly distributed between the eastern and western aisle. The decrease can be attributed to the close proximity of the measurement locations to the fan hub, where the fan blades are less efficient. Note that the configuration of Tests 2 and 3 was identical; therefore, cold flow data was only acquired for Test 2.

Test 4 was conducted with the same configuration used in Tests 2 and 3, except the array height was reduced to 4.6 m (15 ft) resulting in a 7.6 m (25 ft) clearance to the ceiling. Measurements were acquired with the fan operating at both full speed (66 rpm) and half speed (33 rpm). With the fan operating at full speed, the air velocities at the top of the array are similar to those experienced with the higher array used in Tests 2 and 3. The peak downward velocity of 3.1 m/s (10.2 ft/s) was measured at the farthest radial distance from the fan hub. Operating the fan at half speed significantly decreased the air flow, with a peak downward velocity of 1.1 m/s (3.6 ft/s) and an average velocity of approximately 0.5 m/s (1.6 m/s). This represents a 60% to 80% reduction in air velocity.

These data illustrate that the HVLS fan operating at full speed generated a strong downward air velocity at the top of the array regardless of location or clearance to the array. Reducing the fan to half speed significantly decreased the air velocities by as much as 80%. The extent to which the distribution of air flow over the array effects the fire development or sprinkler system performance can not be established without a large-scale fire test.

Table 1: Average cold flow air velocities at top of array for Tests 1-4

Location Identifier	Coordinates* [x,y] m (ft)	Test 1 m/s (ft/s)	Tests 2 and 3† m/s (ft/s)	Test 4 m/s (ft/s)	
W5	-1.2, 1.2 (-4, 4)	-1.8 (-5.9)	-2.9 (-9.5)	-2.6 (-8.5)	-1.1 (-3.6)
W4	-1.2, 0.6 (-4, 2)	-3.8 (-12.5)	-2.5 (-8.2)	-1.8 (-5.9)	-0.6 (-2.0)
W3	-1.2, 0 (-4, 0)	-4.1 (-13.5)	-3.1 (-10.2)	-2.2 (-7.2)	-0.5 (-1.6)
W2	-1.2, -0.6 (-4, -2)	-2.6 (-8.5)	-3.3 (-10.8)	-1.9 (-6.2)	-0.3 (-1.0)
W1	-1.2, -1.2 (-4, -4)	-0.5 (-1.6)	-3.5 (-11.5)	-3.1 (-10.2)	-0.8 (-2.6)
C5	0, 1.2 (0, 4)	-3.0 (-9.8)	-1.4 (-4.6)	-2.2 (-7.2)	-0.9 (-3.0)
C4	0, 0.6 (0, 2)	-2.0 (-6.6)	-0.6 (-2.0)	-1.3 (-4.3)	-0.5 (-1.6)
C3	0, 0 (0, 0)	-4.2 (-13.8)	-1.3 (-4.3)	-1.5 (-4.9)	-0.3 (-1.0)
C2	0, -0.6 (0, -2)	-4.6 (-15.1)	-1.2 (-3.9)	-1.1 (-3.6)	0.0 (0.1)
C1	0, -1.2 (0, -4)	-1.7 (-5.6)	-2.5 (-8.2)	-2.1 (-3.9)	-0.4 (-1.3)
E5	1.2, 1.2 (4, 4)	-2.6 (-8.5)	-3.0 (-9.8)	-3.0 (-9.8)	-1.3 (-4.3)
E4	1.2, 0.6 (4, 2)	-2.7 (-8.9)	-2.0 (-6.6)	-1.8 (-5.9)	-0.8 (-2.6)
E3	1.2, 0 (4, 0)	-3.0 (-9.8)	-2.1 (-3.9)	-1.7 (-5.6)	-0.7 (-2.3)
E2	1.2, -0.6 (4, -2)	-3.1 (-10.2)	-2.7 (-8.9)	-1.7 (-5.6)	-0.6 (-2.0)
E1	1.2, -1.2 (4, -4)	-4.2 (-13.8)	-3.3 (-10.8)	-2.4 (-7.9)	-0.9 (-3.0)
Array height	-	9.1 m (30 ft)	9.1 m (30 ft)	4.6 m (15 ft)	
Fan Speed	-	66 rpm	66 rpm	66 rpm	33 rpm

* Coordinates are relative to the ceiling center (note that the main array was centered below the ceiling)
† The configuration for Tests 2 and 3 were identical; therefore, cold flow data was only acquired for Test 2

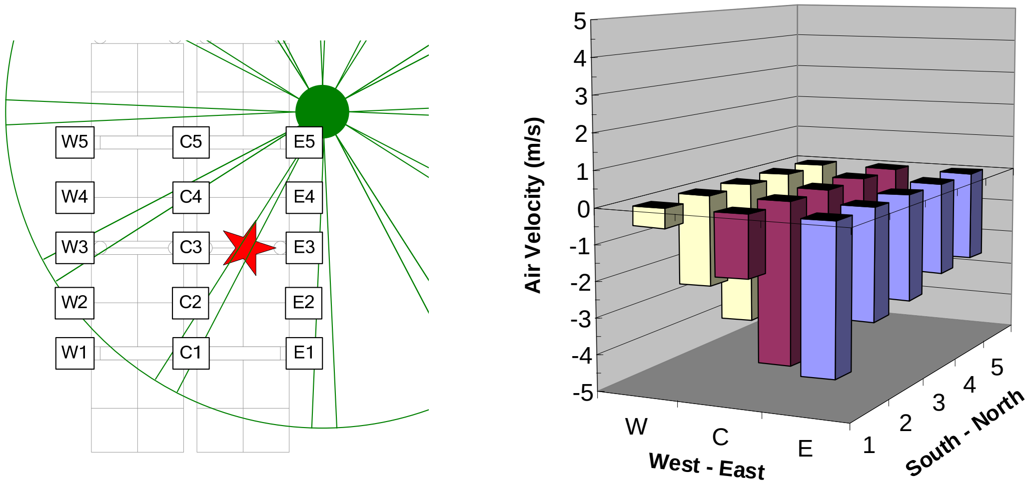


Figure 1: Air flow at top of array [3.2 m (10.5 ft) below ceiling] with the fan operating at 66 rpm for Test 1

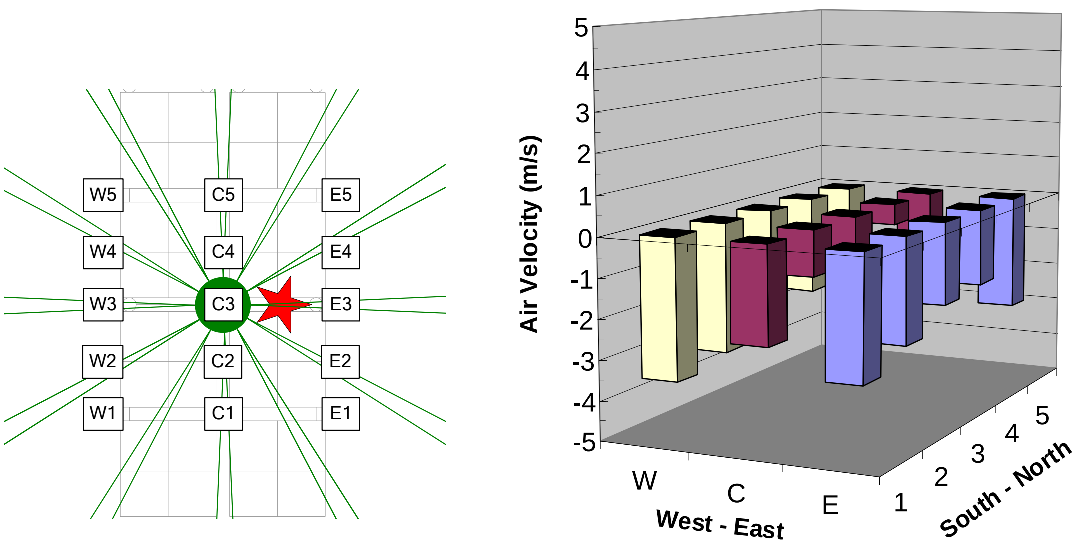


Figure 2: Air flow at top of array [3.2 m (10.5 ft) below ceiling] with the fan operating at 66 rpm for Tests 2 and 3

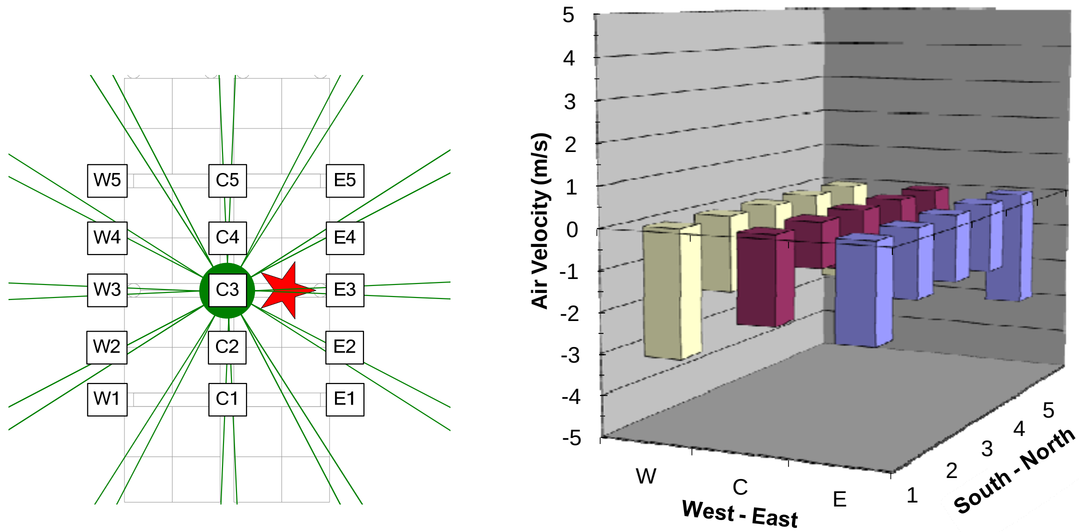


Figure 3: Air flow at top of array [7.8 m (25.5 ft) below ceiling] with the fan operating at 66 rpm for Test 4

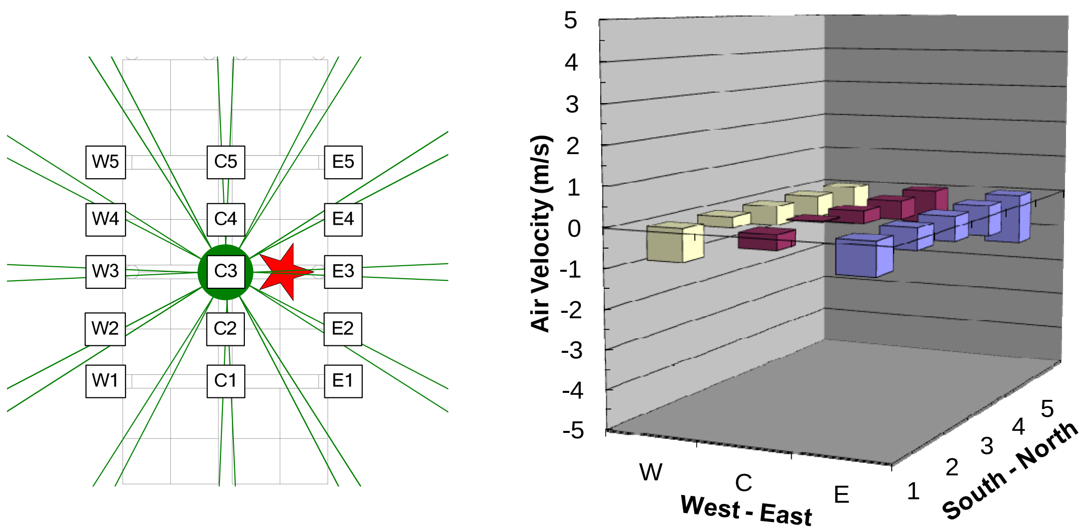


Figure 4: Air flow at top of array [7.8 m (25.5 ft) below ceiling] with the fan operating at 33 rpm for Test 4

APPENDIX D – UNDERWRITERS LABORATORIES FIRE TEST REPORT

Protection of 15-Ft. High Palletized Storage of Group A Plastic Commodity Under 25-40 Ft. Ceilings with an Operating High Volume Low Speed (HVLS) Fan

Technical Report
Underwriters Laboratories Inc.
Project 10CA32386, NC5756

for the

Fire Protection Research Foundation
October 29, 2010
(revised 1/13/2011)

EXECUTIVE SUMMARY

A series of five (5) large-scale fire tests were conducted to develop data regarding the level of protection provided for a palletized storage arrangement of Group A plastic commodity by ceiling sprinklers with an operating High Volume Low Speed (HVLS) 6-blade fan mounted 54.5-in below the ceiling. Two (2) of the tests were conducted with nominal K-14.0 gpm/psi^{½} pendent ESFR sprinklers, and three (3) of the tests were conducted with nominal K-11.2 gpm/psi^{½} upright control mode sprinklers. The palletized storage arrangement of cartoned, unexpanded Group A plastic test commodity to a nominal height of 15-ft was positioned under a 40-ft ceiling for the ESFR tests, and a 30-ft ceiling for the control mode sprinkler tests.

Tests 1 and 2 were conducted with 165°F temperature rated pendent ESFR ceiling sprinklers installed on 10 by 10-ft. spacing with the deflectors positioned 14-in. below the ceiling. A target array was positioned across an 8 ft aisle space to the south of the main array. For both tests, the ceiling sprinkler system was supplied with water resulting in a nominal sprinkler discharge pressure of 75 psi.

Tests 3, 4 and 5 were conducted with 286°F temperature rated standard response upright ceiling sprinklers installed on 8 by 10-ft. spacing with the deflectors positioned 3-in. below the ceiling. A target array was positioned across an 8 ft aisle space to the south of the main array. For these three tests, the ceiling sprinkler system was supplied with water resulting in a nominal sprinkler discharge density of 0.60 gpm/ft^2. These tests also incorporated a simulated interlocking mechanism, including ionization detectors mounted at the ceiling, as well as a VESDA smoke detection system.

Tests 1, 3 and 5 were conducted with the main ignition scenario located between four sprinklers (2 ft in from the fan tip in Test 1 and 3 ft in from the fan tip in Tests 3 and 5). The center of 24-ft HVLS fan located offset from the main array 10-ft south of the ignition location. Each test was conducted for 30 minutes (30:00), and a total of six (Test 1), six (Test 3) and twenty (Test 5) sprinklers operated during the test period. The fire in each test was centered around the center bay above the ignition location and did not spread to either end of the main array or to the adjacent target array.

Tests 2 and 4 were conducted with the main ignition scenario located between four sprinklers (beneath the fan hub in Test 2 and 1 ft offset to the East in Test 4). Both tests were conducted for 30 minutes (30:00), and a total of six (Test 2) and seven (Test 4) sprinklers operated during the test period. The fire in each test was centered around the center bay above the ignition location and did not spread to either end of the main array or to the adjacent target array.

A summary of the parameters and results is presented in Table E1.

FIRE TEST	Test 4 UL-1 (9.15.10)	Test 5 UL-2 (9.17.10)	Test 6 UL-3 (9.21.10)	Test 7 UL-4 (9.23.10)	Test 8 UL-5 (9.27.10)
Parameters					
Location of Test	U.L.	U.L.	U.L.	U.L.	U.L.
Storage Type	Palletized Open Array	Palletized Open Array	Palletized Open Array	Palletized Open Array	Palletized Open Array
Commodity Type	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic
Nominal Storage Height (ft)	15	15	15	15	15
Nominal Ceiling Height (ft)	40	40	25	25	25
Nominal Clearance (ft)	25	25	10	10	10
Aisle Width (in.)	N/A	N/A	N/A	N/A	N/A
Longitudinal/Transverse Flue (in.)	12	12	12	12	12
Ignition Location	Between 4 Sprinklers (centered)	Between 4 Sprinklers (centered)	Between 4 Sprinklers (centered)	Between 4 Sprinklers (centered)	Between 4 Sprinklers (centered)
Ignitor Detail	2 Full Ignitors	2 Full Ignitors	2 Full Ignitors	2 Full Ignitors	2 Full Ignitors
Sprinkler Type/Temperature Rating (°F)	ESFR/165	ESFR/165	CMDA/286	CMDA/286	CMDA/286
Sprinkler Orientation	Pendent	Pendent	Upright	Upright	Upright
Sprinkler Sensitivity	Fast Response	Fast Response	Std. Response	Std. Response	Std. Response
Sprinkler Make/Model Number	Tyco/ESFR-1	Tyco/ESFR-1	Tyco/ELO-231-B	Tyco/ELO-231-B	Tyco/ELO-231-B
Deflector to Ceiling (in.)	14	14	3	3	3
Nominal Sprinkler Discharge Coefficient K (gpm/psi$^{1/2}$)	14	14	11.2	11.2	11.2
Density/Nominal Sprinkler Discharge Pressure (psi)	75	75	0.60 gpm/sq ft	0.60 gpm/sq ft	0.60 gpm/sq ft
Sprinkler Spacing (ft x ft)	10 x 10	10 x 10	8 x 10	8 x 10	8 x 10
Fan Size (ft)	24	24	24	24	24
Fan Location (centered between 4 sprinklers)	Fan Tip 2 ft Beyond Ignition	Hub Above Ignition	Fan Tip 3 ft Beyond Ignition	Hub 1 ft West of Ignition	Fan Tip 3 ft Beyond Ignition
Fan Distance Below Ceiling (in.)	54.5	54.5	54.5	54.5	54.5
HVLS Fan Speed (rpm)	63	63	63	63	63
HVLS Fan Operation	On (no shutdown)	On (no shutdown)	Off at Smoke/Particle Detection Operation(1:36)	Off at Smoke Detection Operation	Off at Waterflow (90 second delay)
HVLS Fan Manufacturer	MacroAir	MacroAir	MacroAir	MacroAir	MacroAir
HVLS Fan Model Name	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL
HVLS Fan Model Number	MA24XL2006	MA24XL2007	MA24XL2008	MA24XL2009	MA24XL2010
HVLS Fan Blade Geometry	Whisperfoil XL	Whisperfoil XL	Whisperfoil XL	Whisperfoil XL	Whisperfoil XL
HVLS Fan Number of Blades	6	6	6	6	6
Results					
Length of Test (hr:min:s)	0:30:00	0:30:00	0:30:00	0:30:00	0:30:00
First Ceiling Sprinkler Operation (min:s)	1:21	1:05	1:36	2:08	1:13
Last Ceiling Sprinkler Operation (min:s)	1:47	1:57	1:58	3:28	3:01
Number of Operated Ceiling Sprinklers	6	6	6	7	20
Peak Gas Temperature at Ceiling Above Ignition (°F)	207	181	1468	504	1506
Maximum 1 Minute Average Gas Temperature at Ceiling Above Ignition (°F)	131	154	1042	360	1287
Peak Steel Temperature at Ceiling Above Ignition (°F)	102	118	244	122	415
Maximum 1 Minute Average Steel Temperature Above Ignition (°F)	100	105	219	122	327
Fire Spread Across Aisle	NO	NO	NO	NO	NO
Fire spread to the Ends of the Array	NO	NO	NO	NO	NO
Fuel Consumed (number of pallets)	25	23	26	15	32
Test Outcome (Pass/Fail)	PASS	PASS	PASS	PASS	
COMMENTS			No delay in fan shutdown after detection operation	Fan blades failed (bent) just after shutdown	Replacement fan used (same model)

Table E1 – Summary of Test Parameters and Results

NOTE

This Report was prepared as an account of a test sponsored by and under the direction of the Fire Protection Research Foundation. In no event shall UL be responsible for whatever use or nonuse is made of the information contained in this Report and in no event shall UL, its employees, or its agents incur any obligation or liability for damages arising out of or in connection with the use, or the inability to use, information contained in this Report.

Table Of Contents

List of Tables

Table Of Figures

INTRODUCTION

This Test Report describes the Special Service Investigation conducted for the Fire Protection Research Foundation to develop fire test data relative to the influence of High Volume Low Speed (HVLS) fans on the level of protection provided for a fire scenario involving palletized storage of cartoned, unexpanded Group A plastic commodity protected by Early Suppression Fast Response (ESFR) sprinklers and standard response control mode sprinklers.

1 TEST FACILITY

The fire tests were conducted in Underwriters Laboratories Inc.'s large-scale fire test facility located in Northbrook, Illinois. The large-scale fire test building used for this investigation includes four fire test areas that are used to develop data on the fire growth and fire suppression characteristics of commodities, as well as the fire suppression characteristics of automatic water sprinkler systems. A schematic of the test facility is shown in Figure 1.

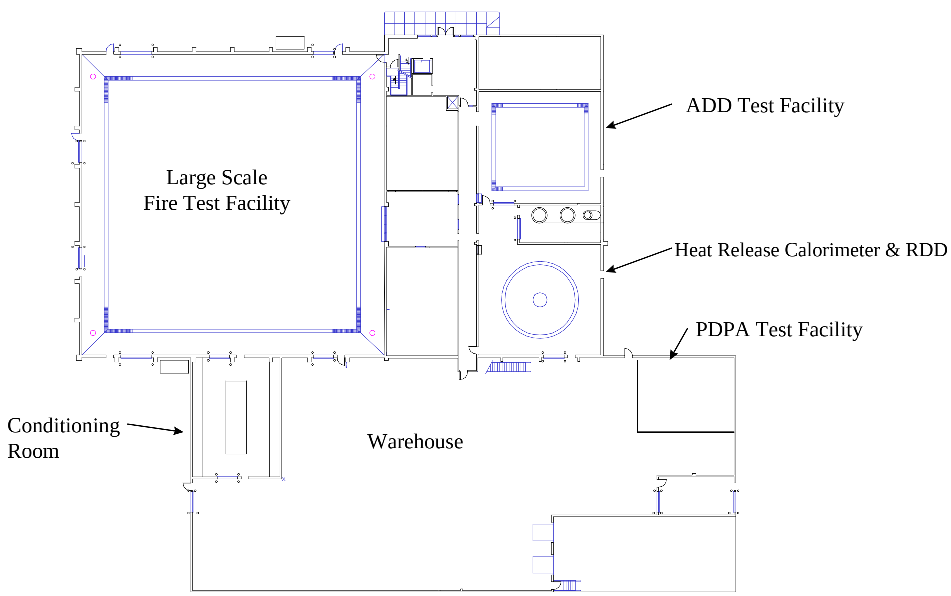


Figure 1 Test Facility

The fire tests were conducted in a 120 by 120 by 54-ft. high room fitted with a 100 x 100-ft adjustable height, smooth, flat, horizontal ceiling. The ceiling was positioned 30-ft above the floor. The test room was equipped with an exhaust system including a regenerative thermal oxidizing (RTO) smoke abatement system. Ambient temperature outside make-up air at approximately 60,000 cfm was provided through four inlet ducts positioned along the walls of the test facility after first sprinkler operation. Prior to first sprinkler operation, ambient temperature outside make-up air was drawn in through the ducts at approximately 30,000 cfm.

The floor of the test facility was smooth, flat and surrounded with a grated drainage trench to insure adequate drainage from the test area. The water runoff from the suppression system drain was collected through a 180,000-gallon water treatment system.

2 EQUIPMENT AND INSTRUMENTATION

2.1 Instrumentation

The instrumentation used in the testing consisted of the following devices:

- One hundred (100) 1/16-in. diameter, Type K inconel sheathed thermocouples located below the ceiling adjacent to each sprinkler
- Three 1/16-in. diameter, Type K inconel sheathed thermocouple located 6, 12 and 18-in. below the ceiling above the ignition location
- Five 1/16-in. diameter, Type K inconel sheathed thermocouples embedded in a 50.5-in. long steel angle attached to the bottom of the ceiling directly above the fire
- A pressure transducer in a 0-100 psi range was used to measure the water pressure in the sprinkler system
- A 12-in. magnetic flow meter in the 0-3200 gpm range was used to measure the water flow rate
- Stopwatches and timing devices located within the data acquisition system were used to monitor and record significant events during the fire test
- Moisture meter to measure the commodity moisture content of the fuel package
- Video and Infrared cameras were used to capture and record images
- Electronic data acquisition system with a one-second-scan rate to obtain the data generated
- Kidde ionization smoke alarms - Model i9070
- VESDA LaserFOCUS smoke detection system

2.2 Sprinkler Systems

2.2.1 TESTS 1 AND 2

One hundred (100) pendent ESFR sprinklers having a 165°F temperature rating and a nominal discharge coefficient (K) of 14.0 gpm/psi$^{1/2}$ were installed on 10 x 10-ft. spacing in a closed head, wet pipe, automatic sprinkler system at the ceiling level. The sprinklers were supplied through a looped piping system consisting of 2 ½-in. diameter branch lines. The sprinklers were positioned with the distance between the deflector and ceiling measured to be 14-in.

The water supply to the ceiling sprinklers was controlled to achieve the parameters shown in Table 1.

Close-up photos of the sprinklers used in this test are shown in Figure 2. A plan view of the sprinkler and instrumentation layout is shown in Figure 3.

Test No.	*Sprinkler Location*	*Nominal flow per sprinkler (gpm)*	*Nominal pressure at sprinkler (psig)*
1	Ceiling	121	75
2	Ceiling	121	75

Table 1 Sprinkler Water Supply Parameters

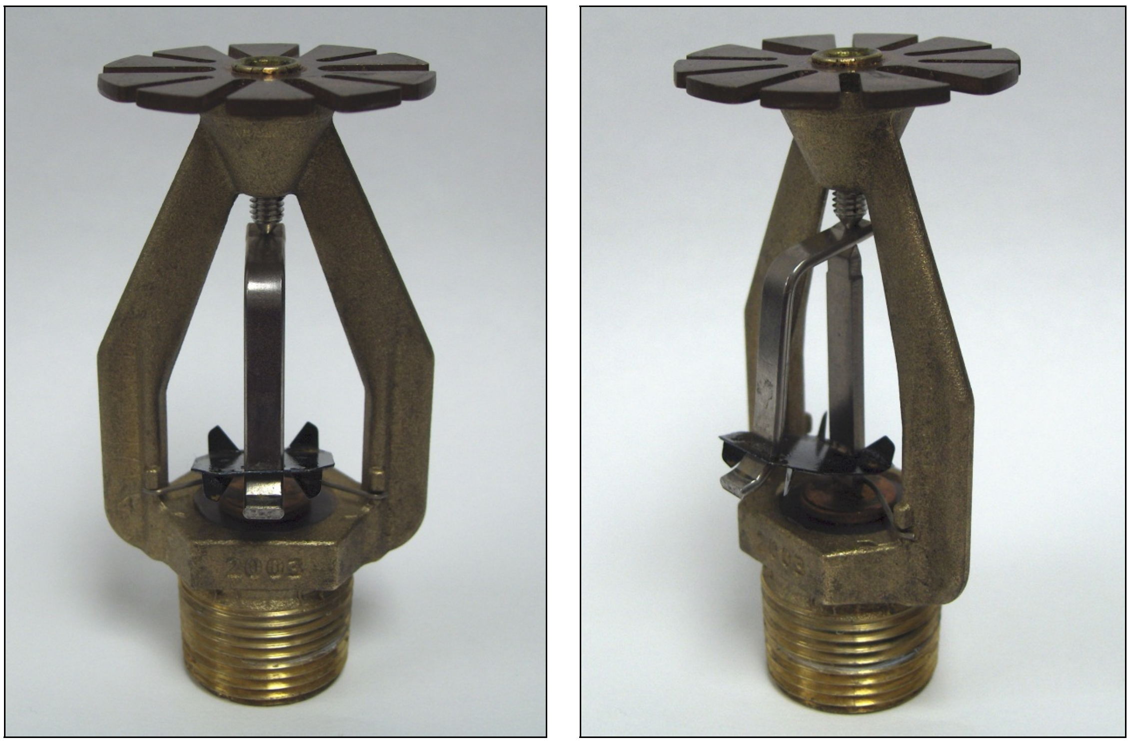


Figure 2 Nominal K=14.0 Pendent ESFR Sprinkler

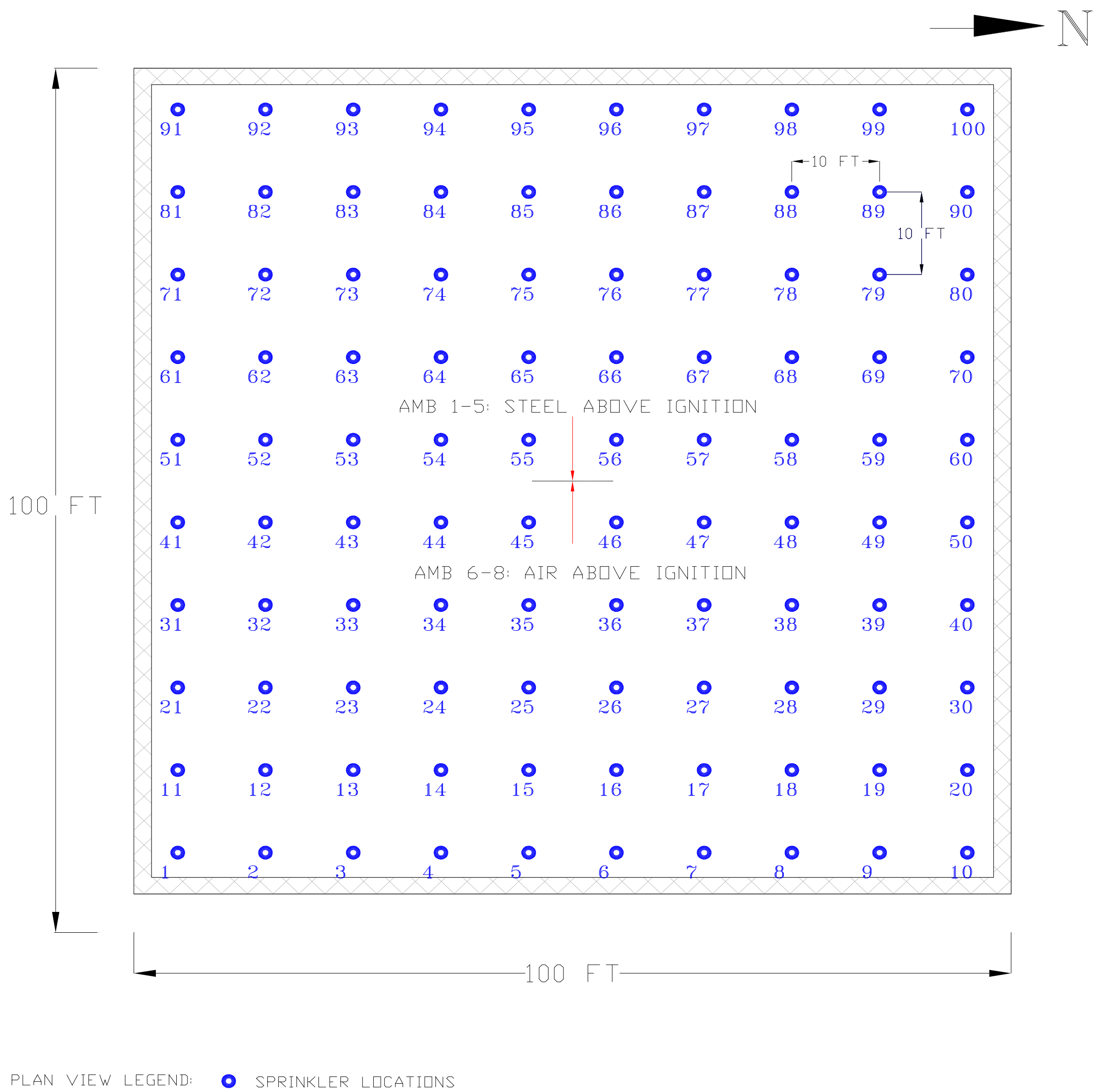


Figure 3 Sprinkler and Instrumentation Locations - Test 1 and 2

2.2.2 TESTS 3, 4 AND 5

One hundred twenty (120) standard response upright control mode sprinklers having a 286°F temperature rating and a nominal discharge coefficient (K) of 11.2 gpm/psi$^{1/2}$ were installed on 8 x 10-ft. spacing in a closed head, wet pipe, automatic sprinkler system at the ceiling level. The sprinklers were supplied through a looped piping system consisting of 2 ½-in. diameter branch lines. The sprinklers were positioned with the distance between the deflector and ceiling measured to be 3-in.

The water supply to the ceiling sprinklers was controlled to achieve the parameters shown in Table 2.

Close-up photos of the sprinklers used in this test are shown in Figure 4. A plan view of the sprinkler and instrumentation layout is shown in Figure 5.

Test No.	***Sprinkler Location***	***Nominal flow per sprinkler (gpm)***	***Nominal pressure at sprinkler (psig)***
3	Ceiling	48	18.4
4	Ceiling	48	18.4
5	Ceiling	48	18.4

Table 2 Sprinkler Water Supply Parameters

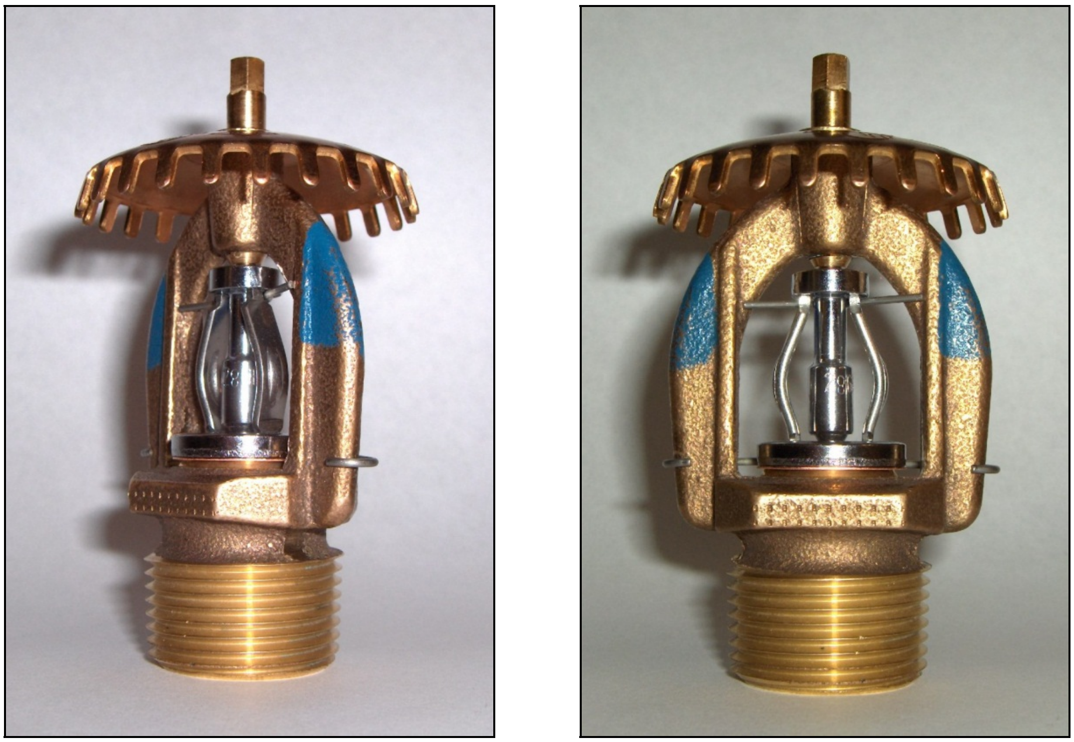


Figure 4 Nominal K=11.2 Upright Sprinkler

Figure 5 Sprinkler and Instrumentation Locations - Test 3, 4, 5

2.3 Wind Velocity

For each test, Baratron velocity probes (see Figure 7) were located 5 ft., 10 ft. and 15 ft. from floor level and positioned at the north end of each flue space as shown in Figure 6. Velocity data for each test arrangement was collected for 3 minutes, both with the storage in place and without the storage in place. The velocity probes were arranged such that the positive side was away from the wind source, and were located to measure velocity in the horizontal plane only.

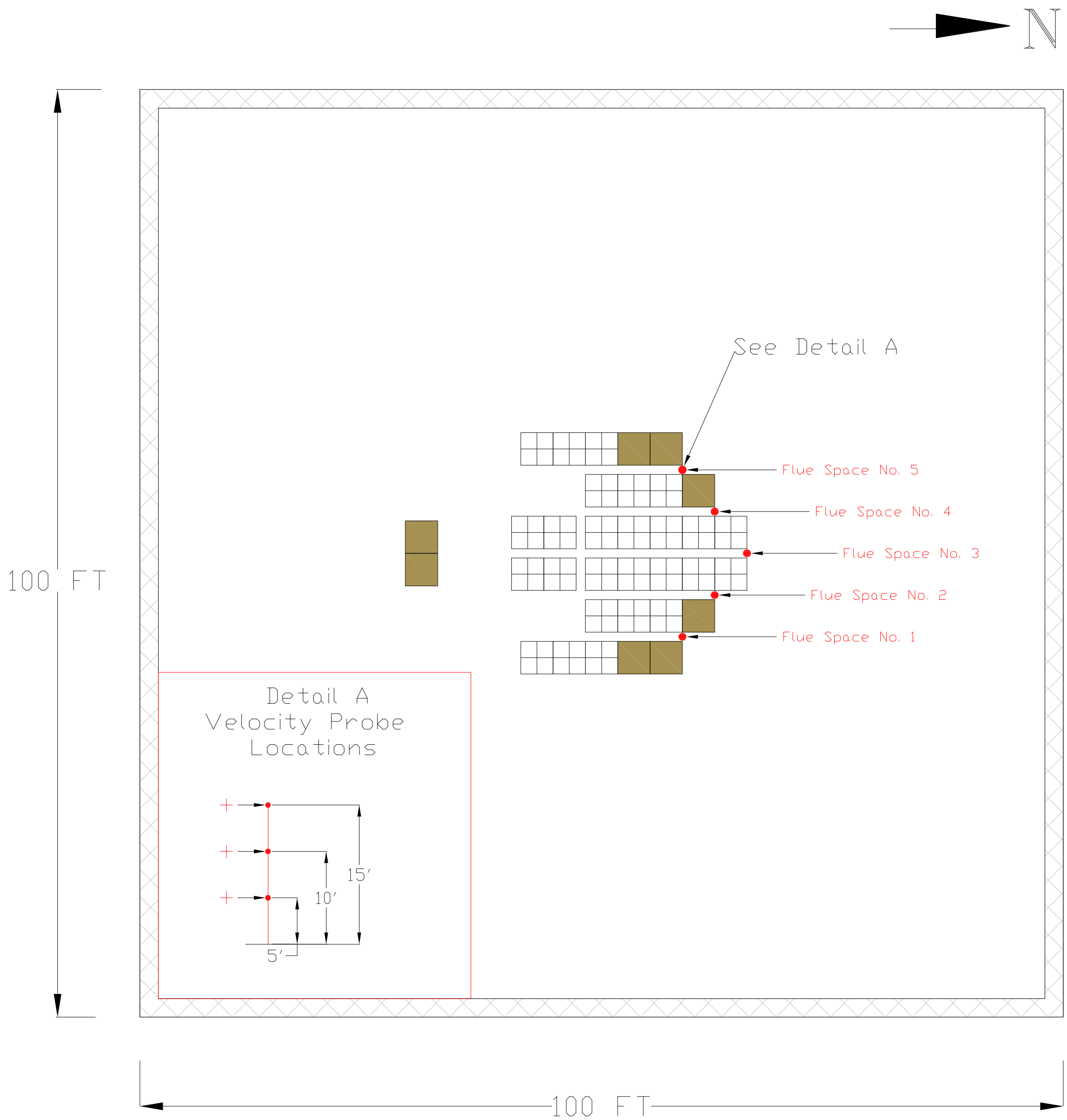


Figure 6 Velocity Probe General Detail

Figure 7 Representative Velocity Probe Installation

2.4 VESDA Smoke Detection

For tests 3, 4 and 5, a VESDA "Laser FOCUS" smoke detection system was installed. This installation consisted of a 4 ft. horizontal 1 in. CPVC sampling tube, mounted 18 in. above the fan motor. A 1 in. by 1 in. by 1 in. TEE at the center of the sampling tube supplied approximately 75 ft. of 1 in. CPVC piping to the VESDA control unit. The sampling tube is shown in Figure 8. The reported sensitivity settings for the VESDA control unit (Figure 9) were as follows:

- ALERT .08%/ft
- ACTION 0.14%/ft
- FIRE 1 0.20%/ft
- FIRE 2 2.0%/ft

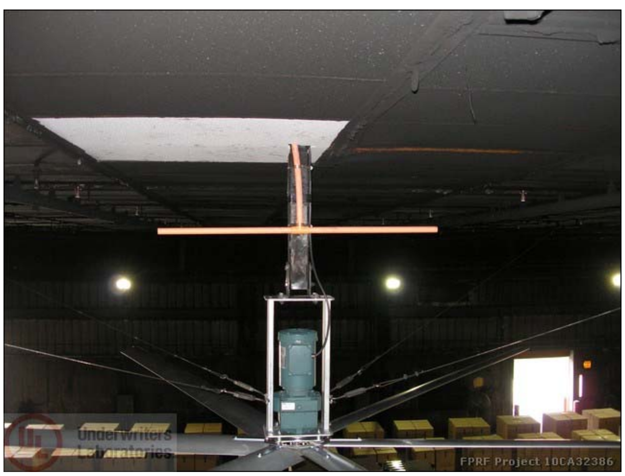


Figure 8 VESDA Sampling Tube

Figure 9 VESDA Control Unit

2.5 Ionization Smoke Detection

For Tests 4 and 5, Kidde Model i9070 Ionization Smoke Alarms were installed at the ceiling. A total of 5 detectors were installed in each test: a single detector was installed above the fan ; and 4 additional detectors were installed on 30 ft. spacing as shown in Figure 10. The reported sensitivity for the Kidde i9070 detectors was 0.59-1.46%/ft.

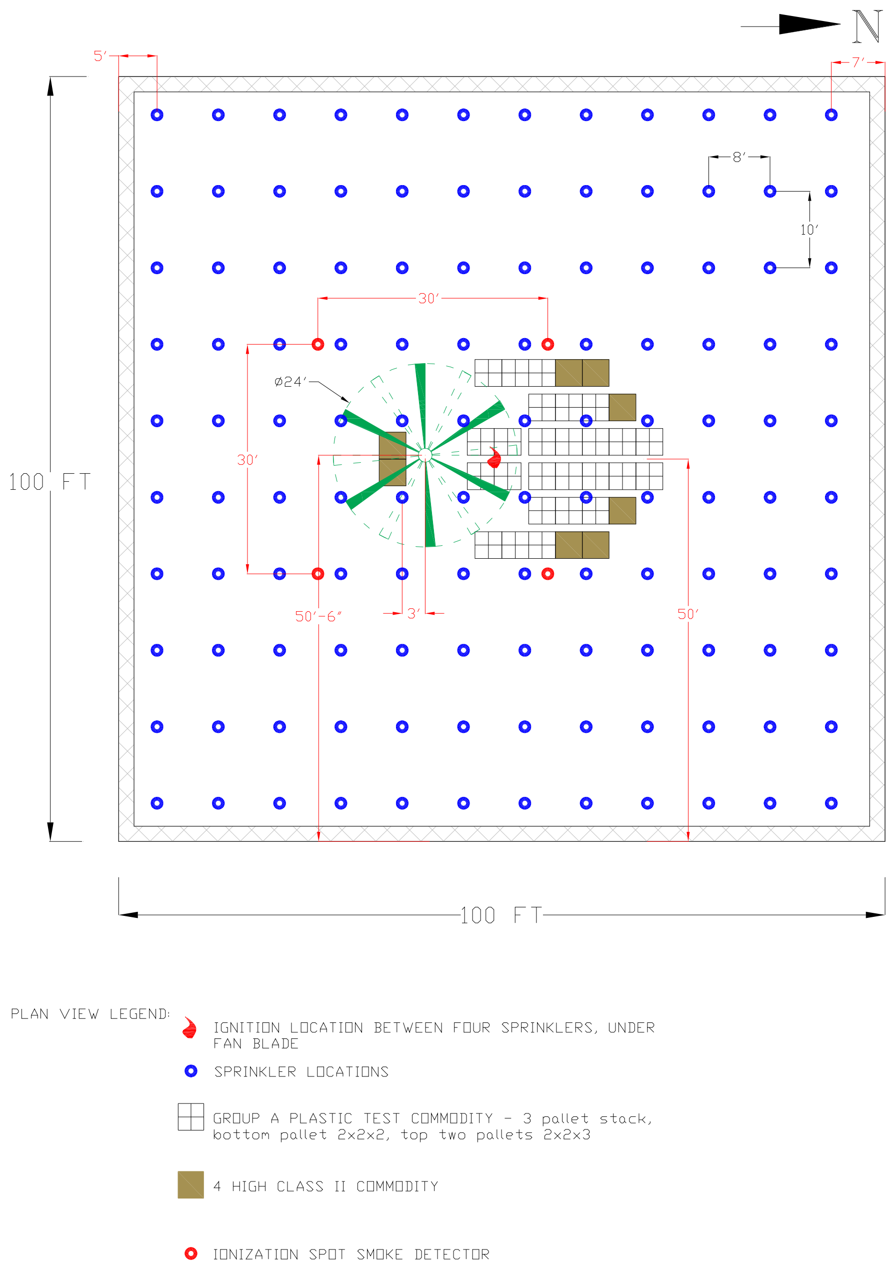


Figure 10 Spot Detection Installation

(for illustration only - Test 5 storage arrangement shown)

3 COMMODITY AND STORAGE ARRANGEMENT – ALL TESTS

The storage arrangement consisted of 20 stacks of Group A commodity and six stacks of Class II commodity. The stacks of Group A commodity were developed using three pallets and 32 cartons, the bottom palletized load contained a double course of four cartons while the top two palletized loads contained a triple course of four cartons. The stacks of Class II commodity were developed using four pallets with four box assemblies. These stacks were placed to have 12 in. flue spaces.

3.1 GROUP A PLASTIC

Single wall corrugated cardboard cartons measured a nominal 21 by 21 by 21-in. and contained 125 crystalline polystyrene (empty, 16 oz size) cups in separated compartments within the carton. The compartmentalization was accomplished with single wall corrugated cardboard sheets to separate the five layers and interlocking single wall corrugated cardboard vertical dividers to separate the five rows and five columns of each layer. Each pallet load is supported by a two-way, 42 in. by 42 in. by 5 in., slatted deck hardwood pallet. A photo of the Group A plastic commodity is shown in Figure 11.

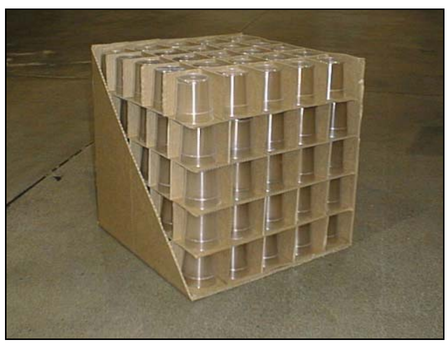


Figure 11 Group A Plastic Commodity

3.2 CLASS II

The Class 2 commodity was constructed from double tri-wall corrugated cardboard cartons with five sided steel stiffeners inserted for stability. Outer carton measurements were 42 by 42 by 42-in. tall on a single 42 by 42 by 5-in. tall hardwood two-way entry pallet. A photo of the Class II commodity is shown in Figure 12.

Figure 12 Class II Commodity

Both box and pallet samples from the test commodity were taken to determine the moisture content. The moisture content for the commodity used is presented in Table 3.

Test No.	***Item***	***Average Moisture Content***
1	Box	8.9
2	Box	8.9
3	Box	11.6
4	Box	11.6
5	Box	7.7

Table 3 Moisture Content of Group A Plastic Commodity

3.3 HVLS Fan Arrangement

A MacroAir "MaxAir" Whisperfoil XL High Volume Low Speed (HVLS) 6-blade fan with a 24-ft diameter was installed in the test cell, with the fan hub mounted 54.5-in below the ceiling for all tests. The fan operated such that the air movement was in the downward direction, and the variable speed motor drive was arranged for the fan to operate at maximum speed (63 RPM).

3.4 Test 1 Arrangement

3.4.1 STORAGE ARRANGEMENT – TEST 1

The storage arrangement consisted of 20 stacks of Group A commodity and six stacks of Class II commodity. The stacks of Group A commodity were developed using three pallets and 32 cartons. The bottom palletized load contained a double course of four cartons while the top two palletized loads contained a triple course of four cartons. The stacks of Class II commodity were developed using four pallets with four box assemblies. These stacks were placed to have 12 in. flue spaces. Test setup photos are presented in Figure 35.

The commodity storage height was a nominal 15 ft. and placed under a ceiling positioned 40 ft. above the floor. The placement of the fan in the ceiling was arranged to be centrally located between the four sprinklers directly adjacent to the four sprinklers above ignition. The distance from the top of the commodity to the sprinkler deflector was set at 25 feet.

The HVLS fan was positioned with the center of the 24-ft HVLS fan located above the main array 10-ft south of the ignition location, with the fan hub positioned 54.5-in below the ceiling as shown in Figure 13, Figure 14 and Figure 15.

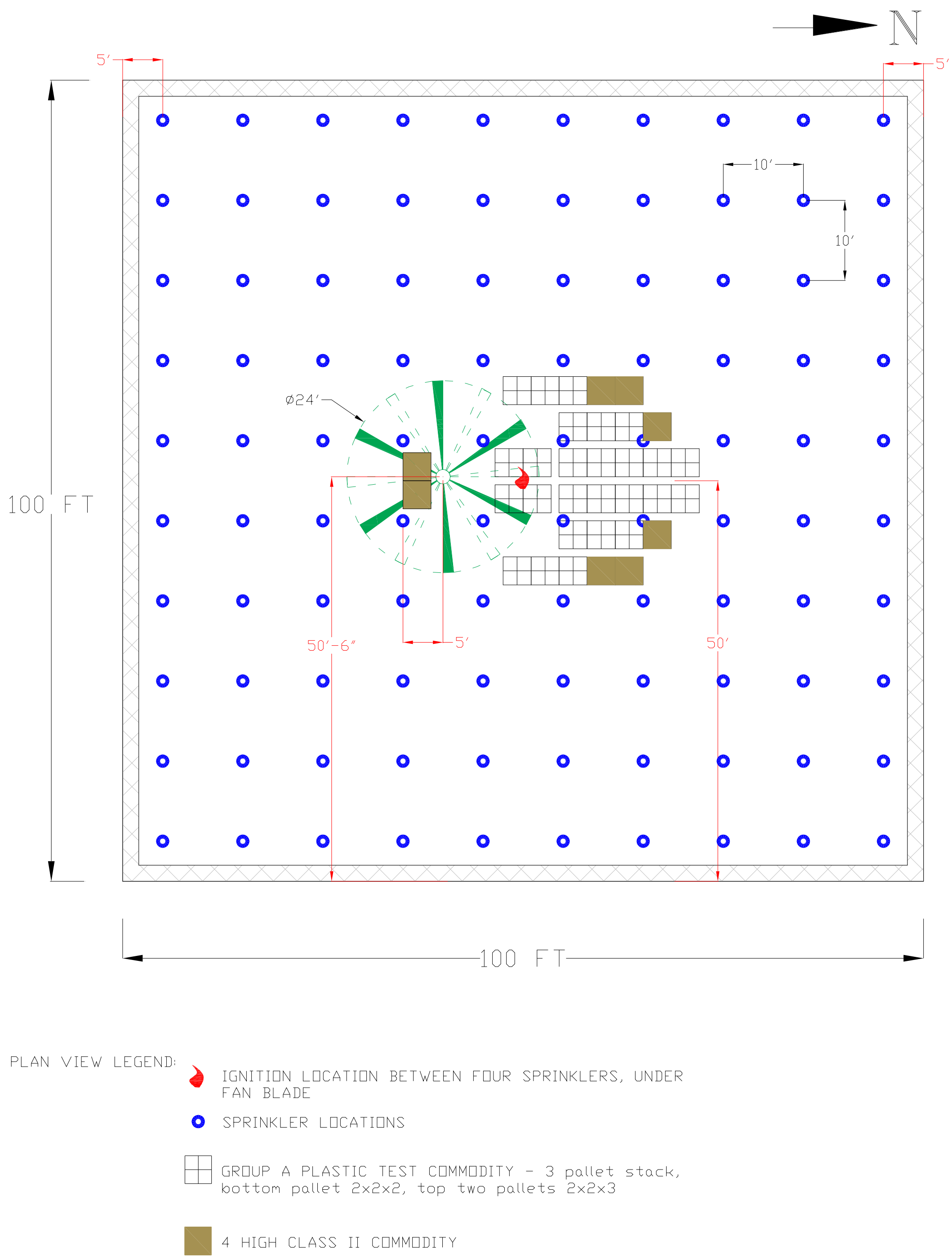


Figure 13 Test 1 Storage / Fan Arrangement Plan View

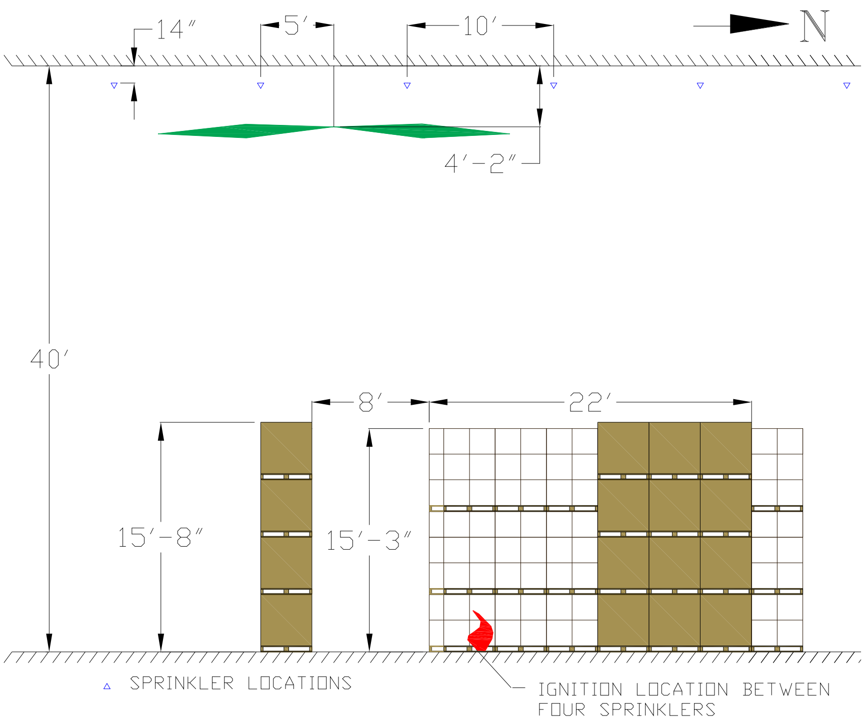


Figure 14 Test 1 East / West Elevation View

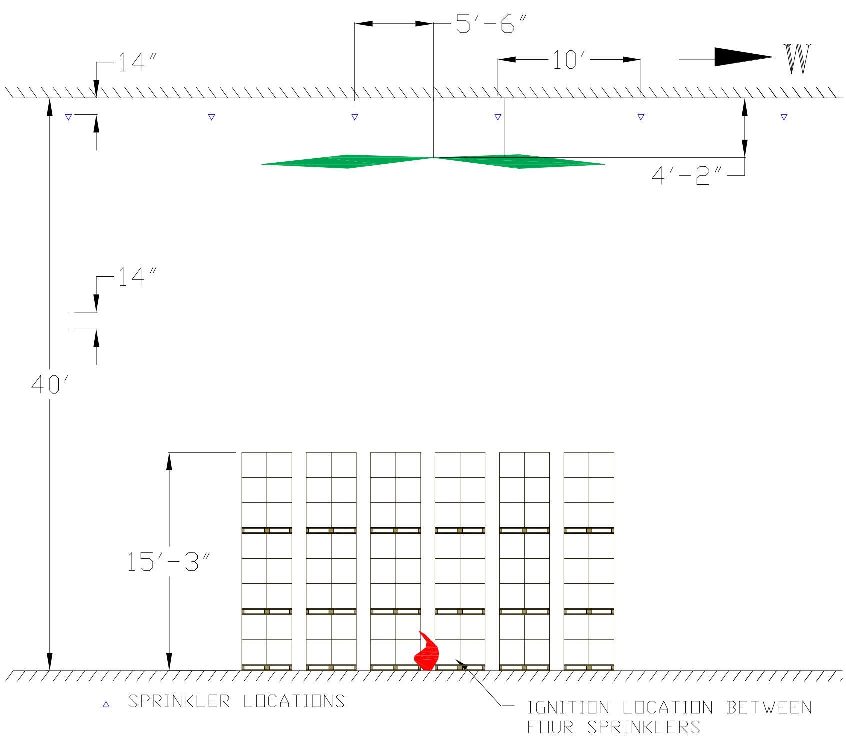


Figure 15 Test 1 North / South Elevation View

3.4.2 IGNITION METHOD – TEST 1

Ignition was accomplished by using two full-standard cellulose cotton igniters. The igniters were constructed from 3 in. by 6 in. long cellulosic bundles each soaked with 8 oz. of gasoline and wrapped in a polyethylene bags. The igniters were positioned 4 1/2-in off the floor and located in the longitudinal flue at the center of the main array, as shown in Figure 16.

Figure 16 Test 1 Ignition Detail

3.5 Test 2 Arrangement

3.5.1 STORAGE ARRANGEMENT – TEST 2

The storage arrangement consisted of 20 stacks of Group A commodity and six stacks of Class II commodity. The stacks of Group A commodity were developed using three pallets and 32 cartons. The bottom palletized load contained a double course of four cartons while the top two palletized loads contained a triple course of four cartons. The stacks of Class II commodity were developed using four pallets with four box assemblies. These stacks were placed to have 12 in. flue spaces. Test setup photos are presented in Figure 36.

The commodity storage height was a nominal 15 ft. and placed under a ceiling positioned 40 ft. above the floor. The placement of the fan in the ceiling was arranged to be centrally located between the four sprinklers directly above ignition. The distance from the top of the commodity to the sprinkler deflector was set at 25 feet.

The HVLS fan was positioned with the center of the 24-ft HVLS fan located above the ignition location, with the fan hub positioned 54.5-in below the ceiling as shown in Figure 17, Figure 18and Figure 19.

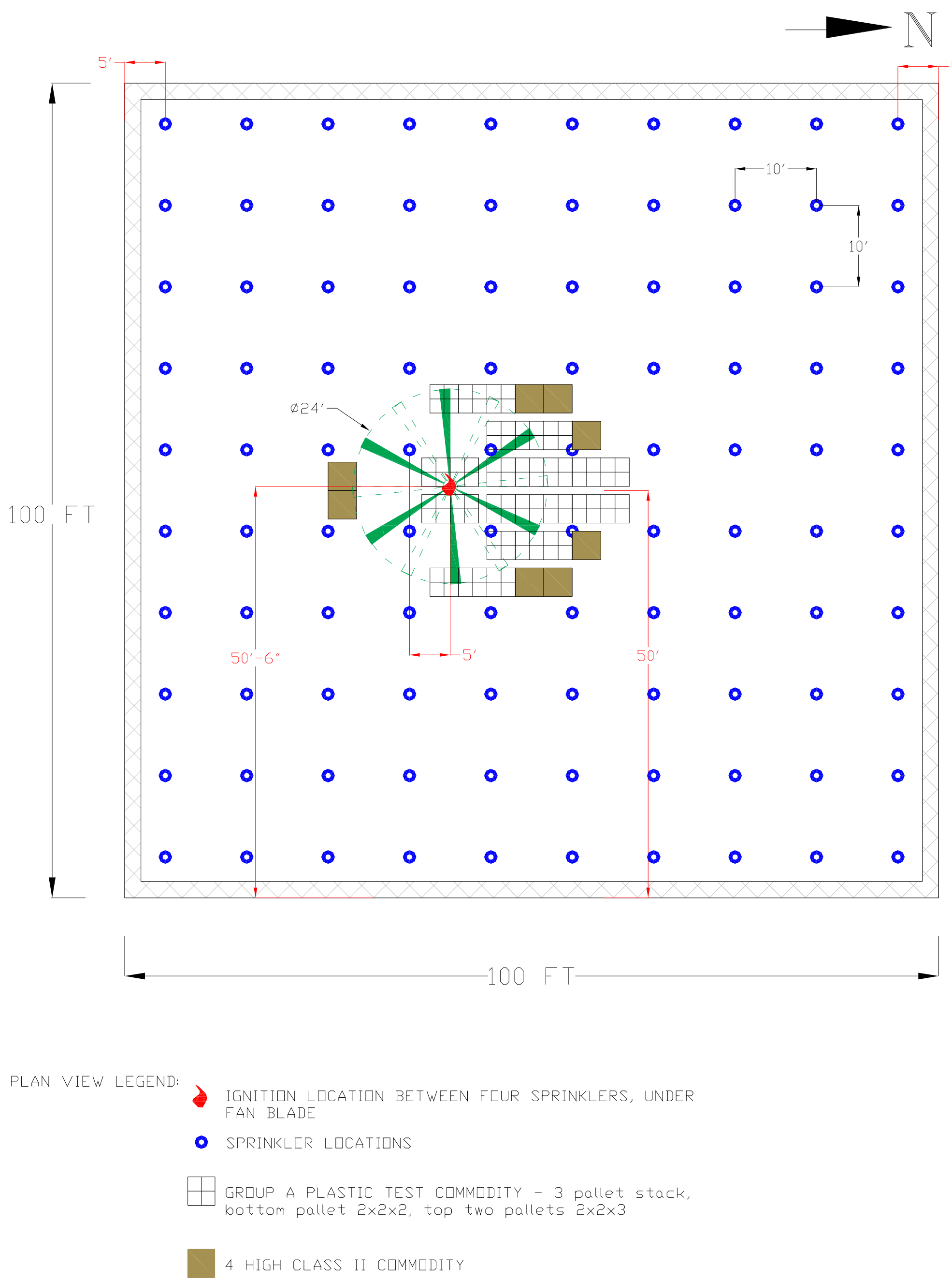


Figure 17 Test 2 Storage / Fan Arrangement Plan View

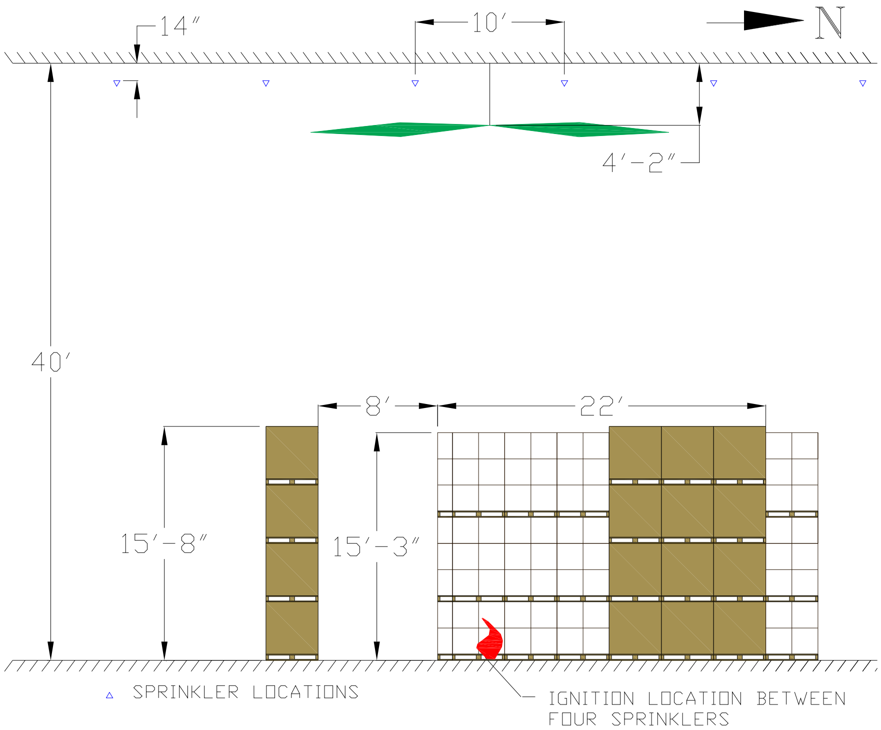


Figure 18 Test 2 East / West Elevation View

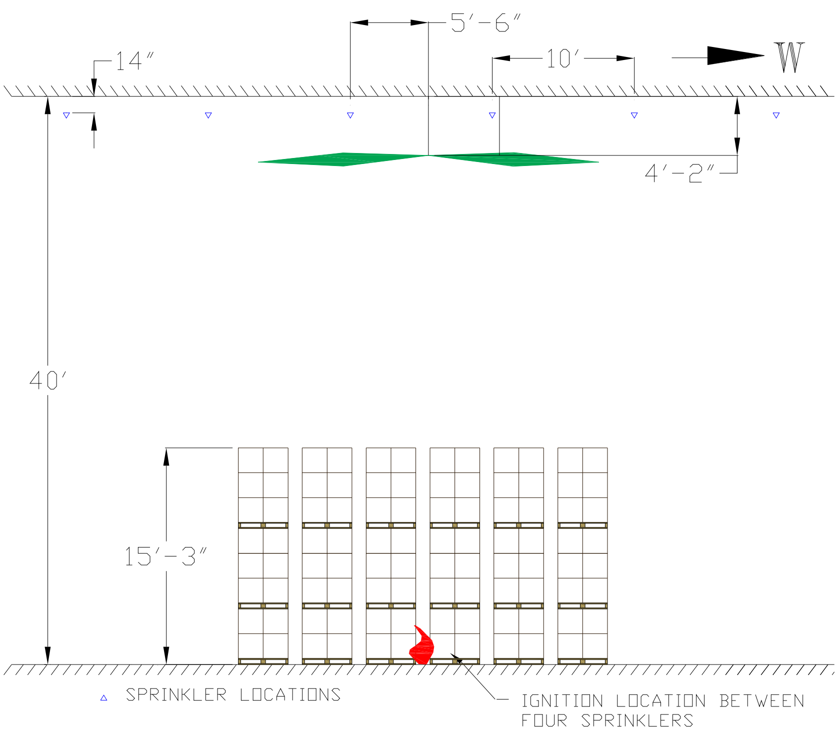


Figure 19 Test 2 North / South Elevation View

3.5.2 IGNITION METHOD – TEST 2

Ignition was accomplished by using two full-standard cellulose cotton igniters. The igniters were constructed from 3 in. by 6 in. long cellulosic bundles each soaked with 8 oz. of gasoline and wrapped in a polyethylene bags. The igniters were positioned 4 1/2-in off the floor and located in the longitudinal flue at the center of the main array, as shown in Figure 20.

Figure 20 Test 2 Ignition Detail

3.6 Test 3 Arrangement

3.6.1 STORAGE ARRANGEMENT – TEST 3

The storage arrangement consisted of 20 stacks of Group A commodity and six stacks of Class II commodity. The stacks of Group A commodity were developed using three pallets and 32 cartons. The bottom palletized load contained a double course of four cartons while the top two palletized loads contained a triple course of four cartons. The stacks of Class II commodity were developed using four pallets with four box assemblies. These stacks were placed to have 12 in. flue spaces. Test setup photos are presented in Figure 37.

The commodity storage height was a nominal 15 ft. and placed under a ceiling positioned 25 ft. above the floor. The placement of the fan in the ceiling was arranged to be centrally located between the four sprinklers directly adjacent to the four sprinklers above ignition. The distance from the top of the commodity to the sprinkler deflector was set at 4 1/2 feet.

The HVLS fan was positioned with the center of 24-ft HVLS fan located above the main array 10-ft south of the ignition location, with the fan hub positioned 54.5-in below the ceiling as shown in Figure 21, Figure 22 and Figure 23.

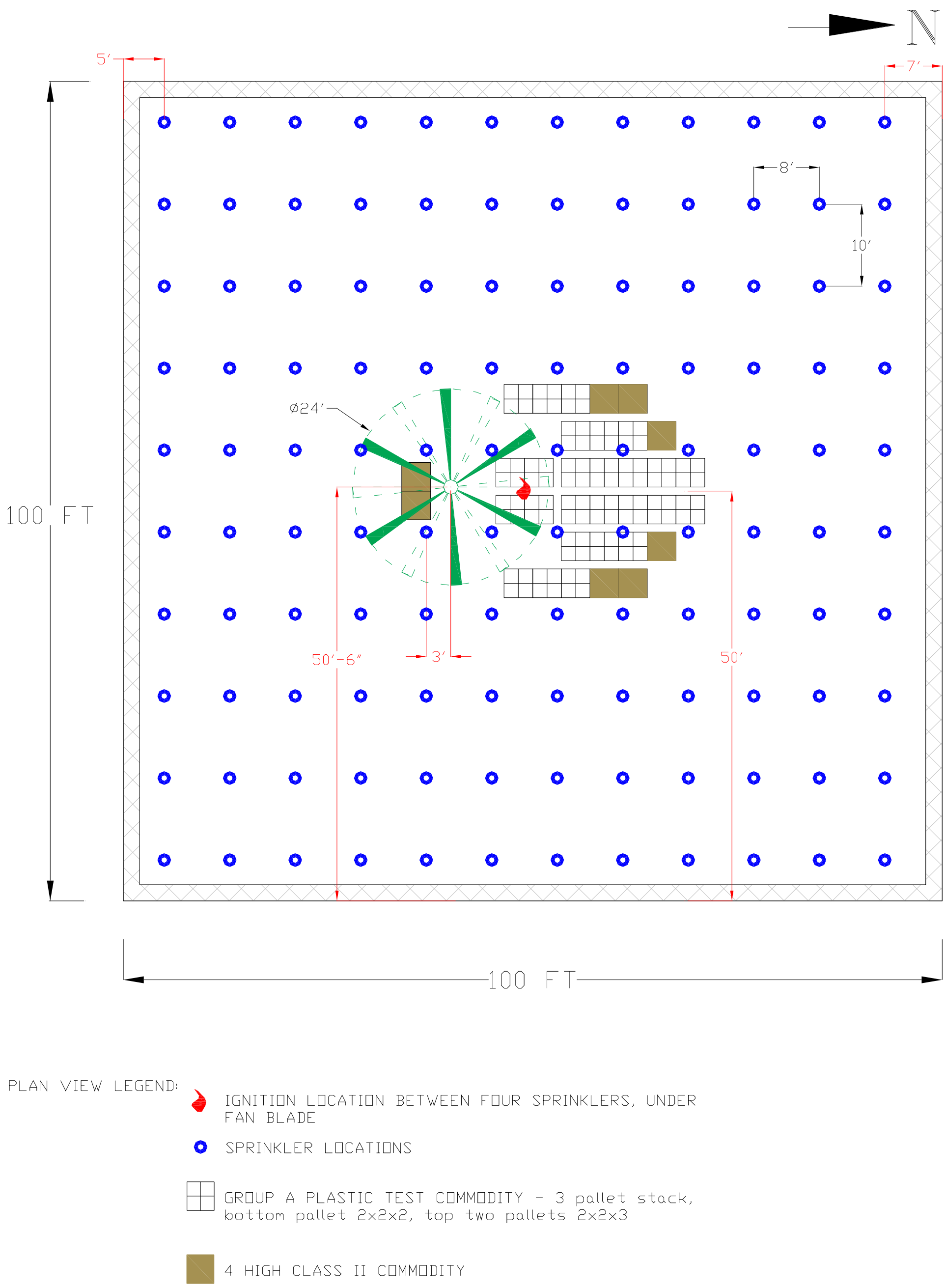


Figure 21 Test 3 Storage / Fan Arrangement Plan View

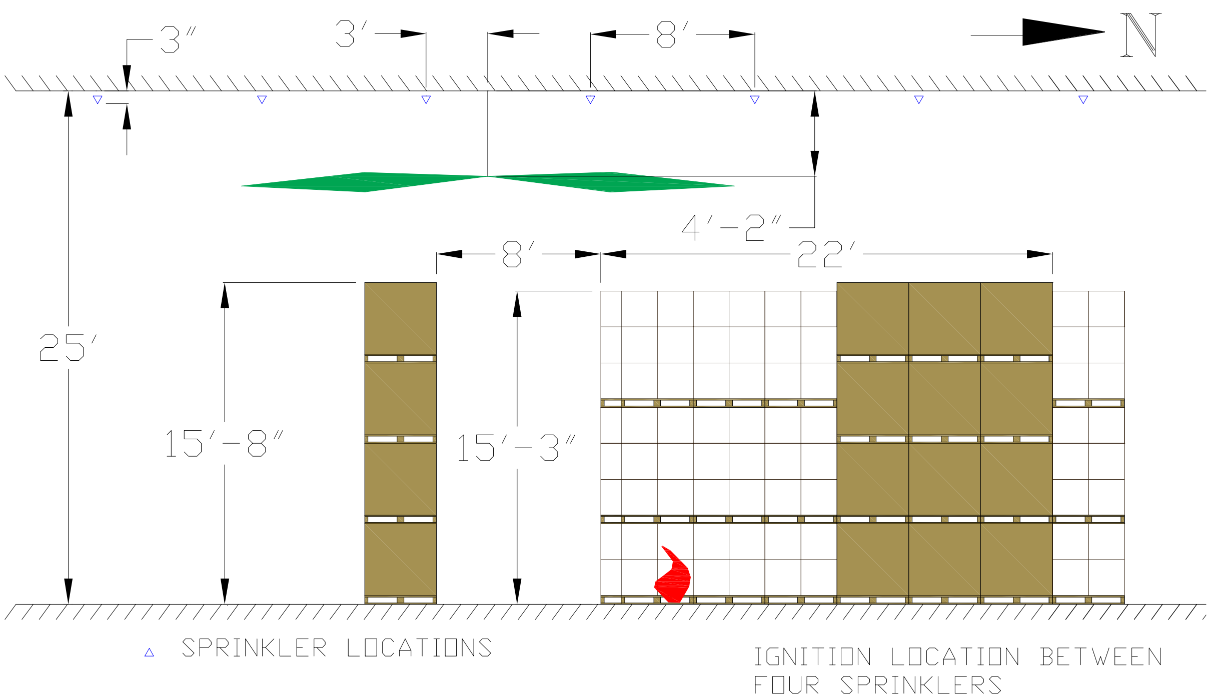


Figure 22 Test 3 East / West Elevation View

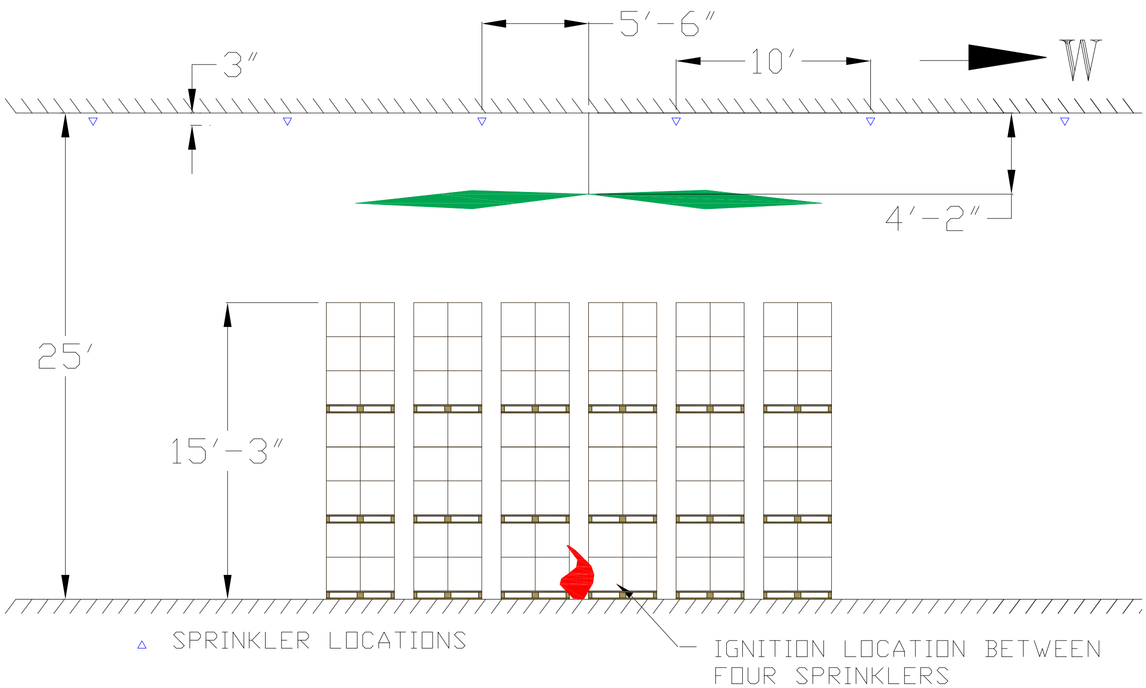


Figure 23 Test 3 North / South Elevation View

3.6.2 IGNITION METHOD – TEST 3

Ignition was accomplished by using two full-standard cellulose cotton igniters. The igniters were constructed from 3 in. by 6 in. long cellulosic bundles each soaked with 8 oz. of gasoline and wrapped in a polyethylene bags. The igniters were positioned 10-in off the floor and located in the longitudinal flue at the center of the main array, as shown in Figure 24.

Figure 24 Test 3 Ignition Detail

3.7 Test 4 Arrangement

3.7.1 STORAGE ARRANGEMENT – TEST 4

The storage arrangement consisted of 20 stacks of Group A commodity and six stacks of Class II commodity. The stacks of Group A commodity were developed using three pallets and 32 cartons. The bottom palletized load contained a double course of four cartons while the top two palletized loads contained a triple course of four cartons. The stacks of Class II commodity were developed using four pallets with four box assemblies. These stacks were placed to have 12 in. flue spaces. Test setup photos are presented in Figure 38.

The commodity storage height was a nominal 15 ft. and placed under a ceiling positioned 25 ft. above the floor. The placement of the fan in the ceiling was arranged to be centrally located between the four sprinklers directly above ignition. The distance from the top of the commodity to the sprinkler deflector was set at 10 feet.

The HVLS fan was positioned with the center of 24-ft HVLS fan located above the main array ignition location, with the fan hub positioned 54.5-in below the ceiling as shown in Figure 25, Figure 26 and Figure 27.

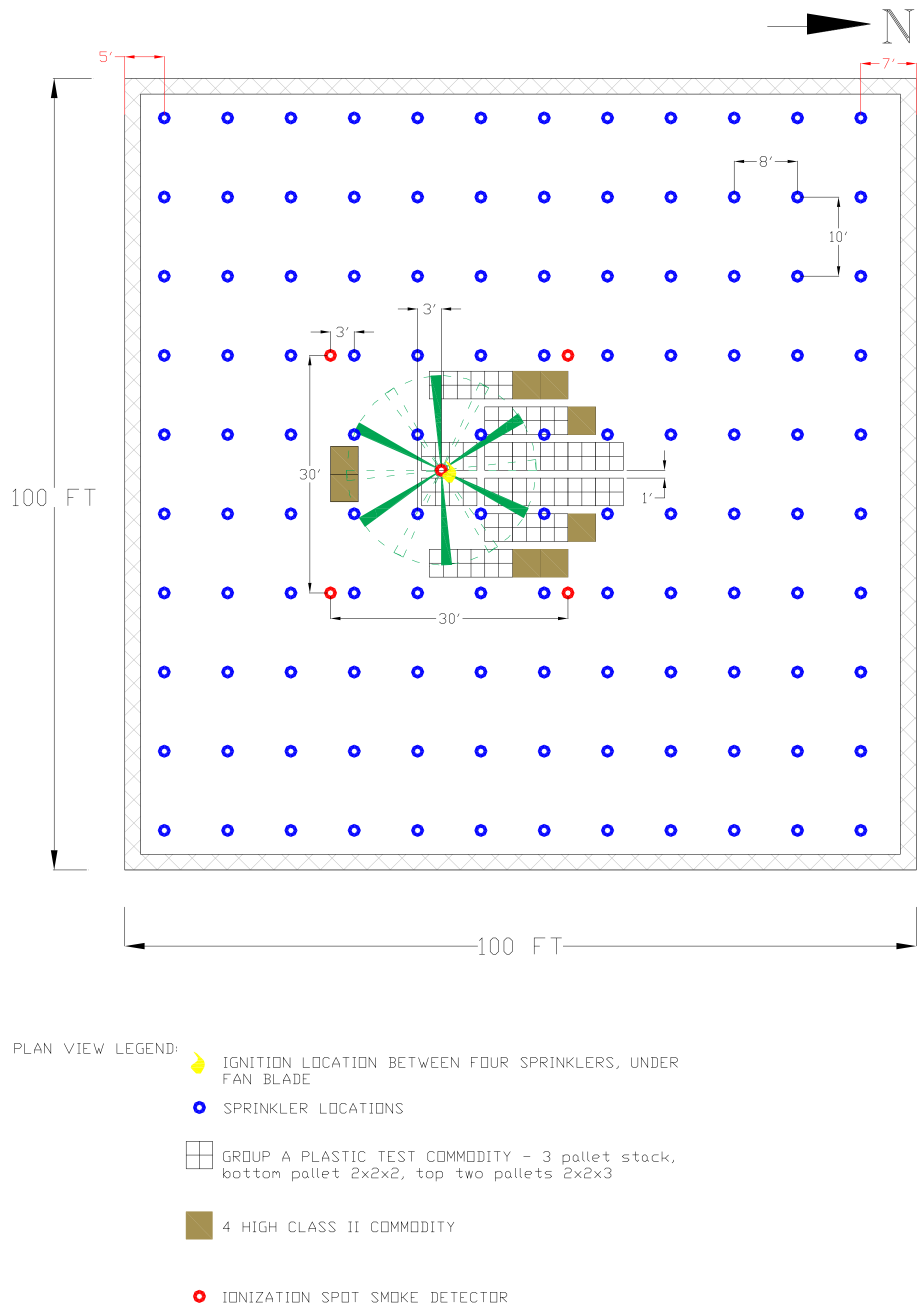


Figure 25 Test 4 Storage / Fan Arrangement Plan View

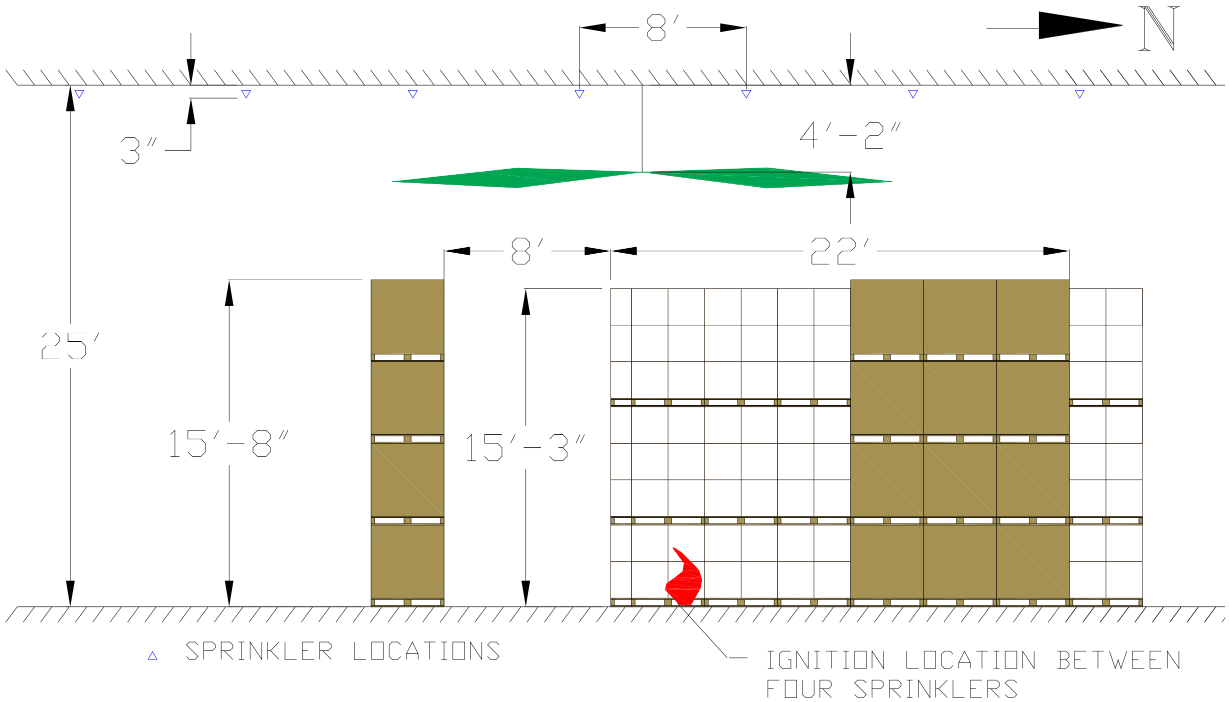


Figure 26 Test 4 East / West Elevation View

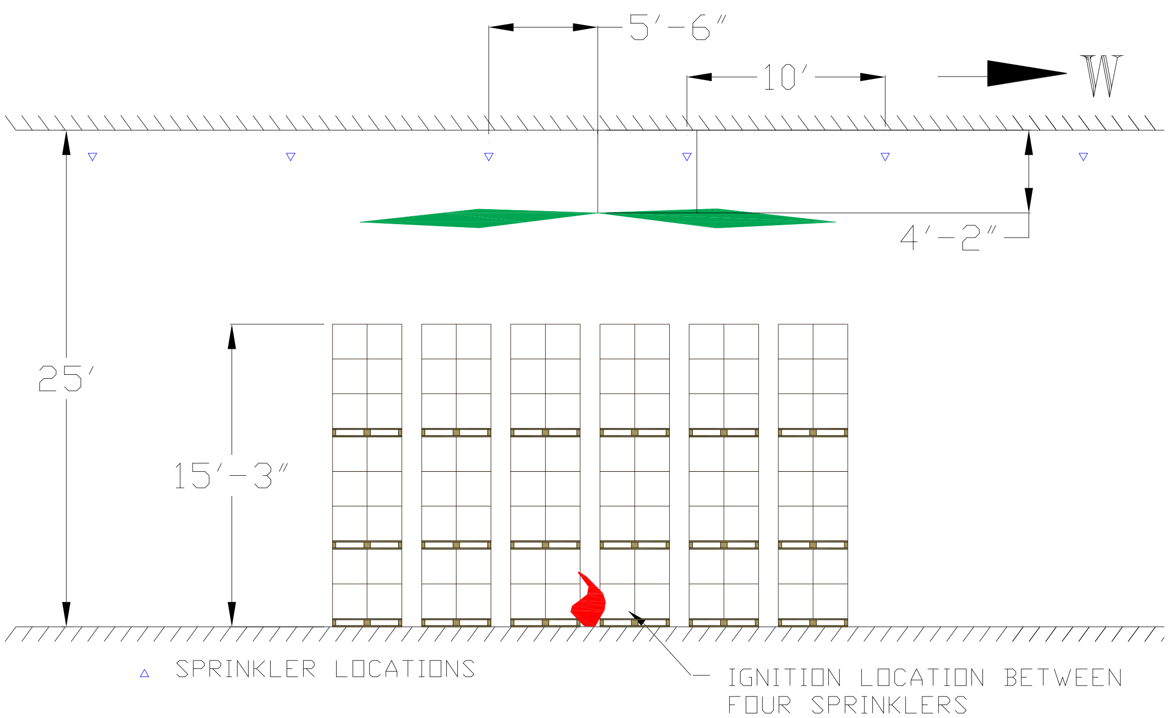


Figure 27 Test 4 North / South Elevation View

3.7.2 IGNITION METHOD – TEST 4

Ignition was accomplished by using two full-standard cellulose cotton igniters. The igniters were constructed from 3 in. by 6 in. long cellulosic bundles each soaked with 8 oz. of gasoline and wrapped in a polyethylene bags. The igniters were positioned 10-in off the floor and located in the longitudinal flue at the center of the main array, as shown in Figure 28.

Figure 28 Test 4 Ignition Detail

3.8 Test 5 Arrangement

3.8.1 STORAGE ARRANGEMENT – TEST 5

The storage arrangement consisted of 20 stacks of Group A commodity and six stacks of Class II commodity. The stacks of Group A commodity were developed using three pallets and 32 cartons. The bottom palletized load contained a double course of four cartons while the top two palletized loads contained a triple course of four cartons. The stacks of Class II commodity were developed using four pallets with four box assemblies. These stacks were placed to have 12 in. flue spaces. Test setup photos are presented in Figure 39.

The commodity storage height was a nominal 15 ft. and placed under a ceiling positioned 25 ft. above the floor. The placement of the fan in the ceiling was arranged to be centrally located between the four sprinklers directly adjacent to the four sprinklers above ignition. The distance from the top of the commodity to the sprinkler deflector was set at 10 feet.

The HVLS fan was positioned with the center of 24-ft HVLS fan located above the main array 10-ft south of the ignition location, with the fan hub positioned 54.5-in below the ceiling as shown in Figure 29, Figure 30 and Figure 31. Note that due to the fan blade failure in Test 4, a replacement fan motor and blades of the same model were used for this test.

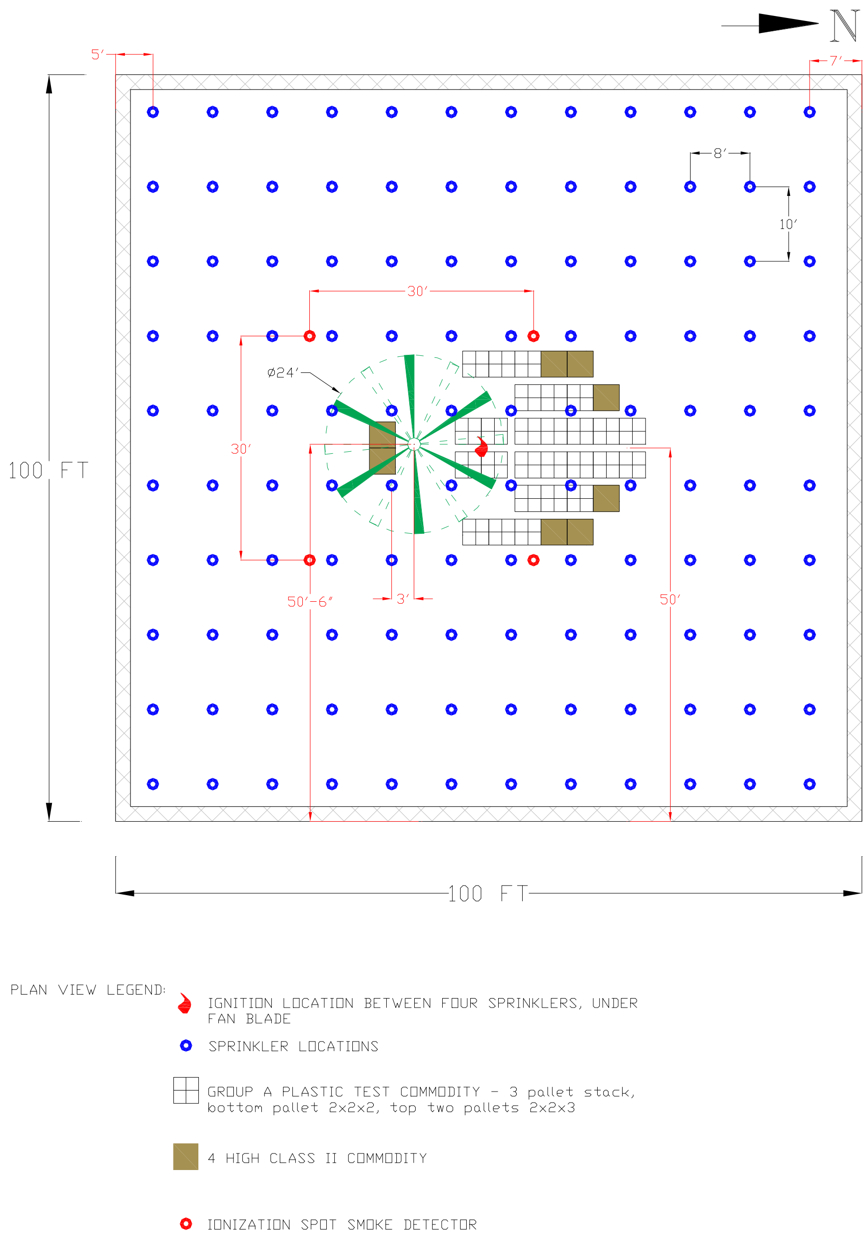


Figure 29 Test 5 Storage / Fan Arrangement Plan View

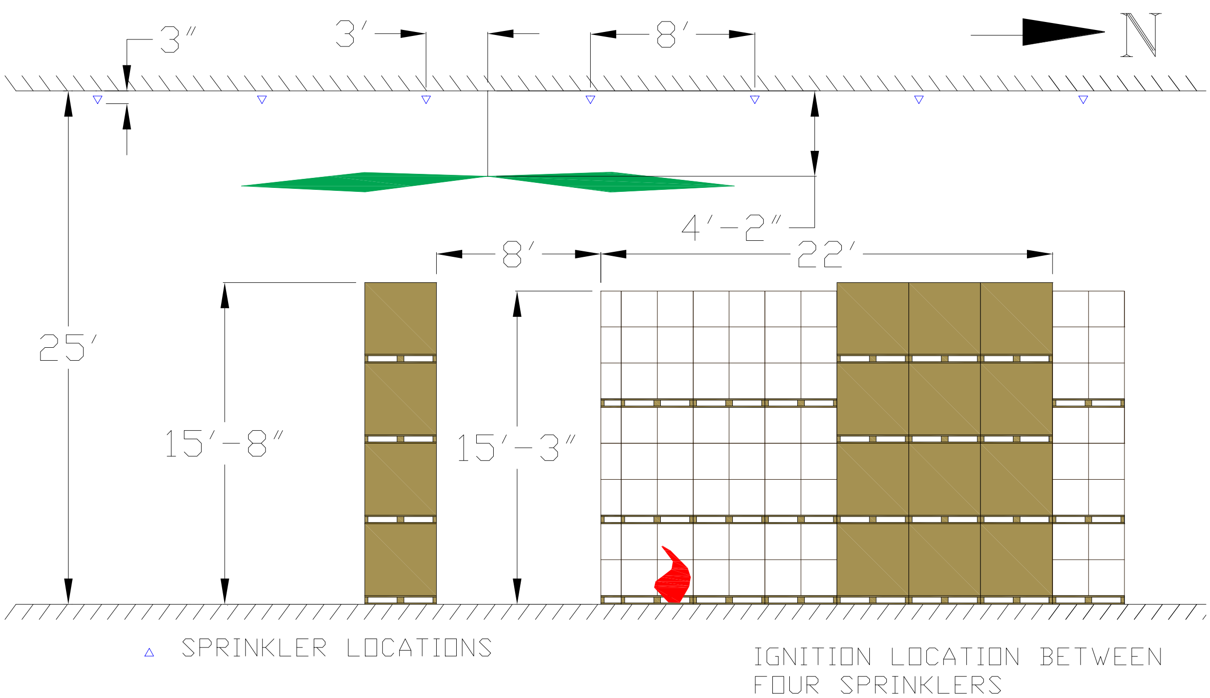


Figure 30 Test 5 East / West Elevation View

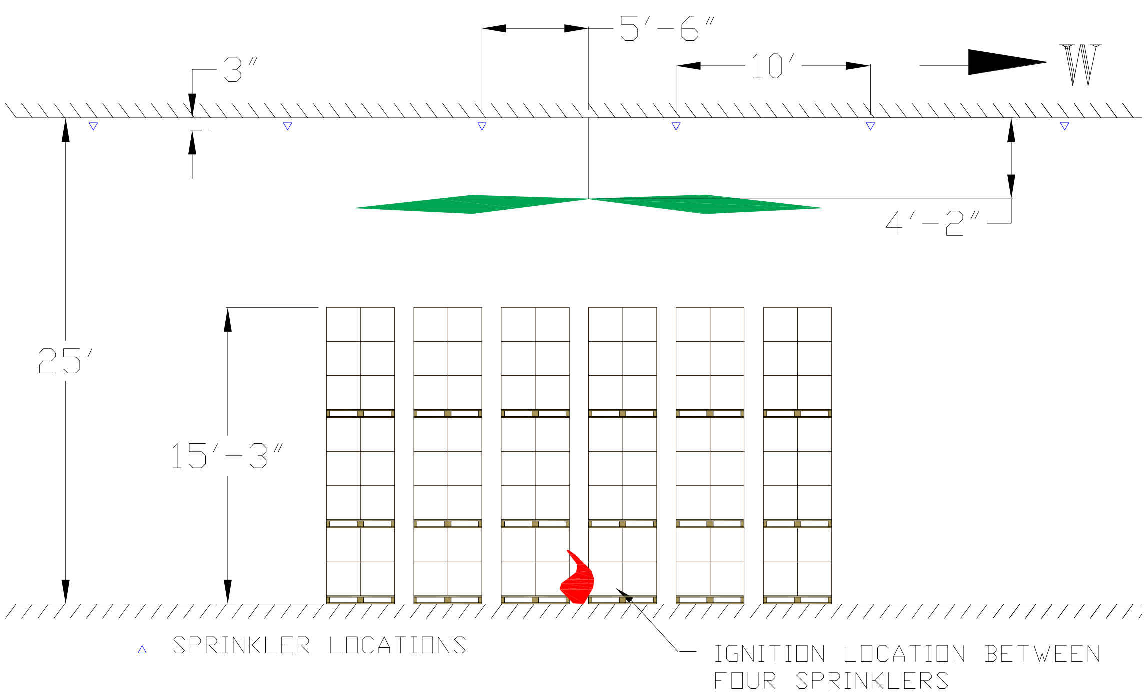


Figure 31 Test 5 North / South Elevation View

3.8.2 IGNITION METHOD – TEST 5

Ignition was accomplished by using two full-standard cellulose cotton igniters. The igniters were constructed from 3 in. by 6 in. long cellulosic bundles each soaked with 8 oz. of gasoline and wrapped in a polyethylene bags. The igniters were positioned 4 1/2-in off the floor and located in the longitudinal flue at the center of the main array, as shown in Figure 32.

Figure 32 Test 5 Ignition Detail

4 TEST PHOTOS AND RESULTS

4.1 Wind Velocity

			Flue Space Number														
			1			2			3			4			5		
			Velocity Probe Elevation														
			5 ft	10 ft	15 ft	5 ft	10 ft	15 ft	5 ft	10 ft	15 ft	5 ft	10 ft	15 ft	5 ft	10 ft	15 ft
			Velocity (m/s)														
Test No.	1	w/stge	2.417	1.650	no data	2.020	1.641	0.271	2.286	1.905	-0.894	2.525	2.064	0.035	2.469	1.870	-0.245
		w/o stge	0.692	0.126	0.176	0.544	-0.034	0.107	0.412	0.076	0.181	0.437	-0.194	-0.046	0.134	-0.218	-0.076
	2	w/stge	2.415	1.827	0.007	2.241	2.054	2.907	2.932	2.800	2.076	3.101	3.104	2.610	2.843	2.753	1.859
		w/o stge	0.478	-0.225	-0.280	0.645	-0.157	-0.105	no data	no data	no data	0.995	0.063	0.073	1.288	0.298	-0.061
	3	w/stge	2.038	1.378	0.610	1.807	1.479	0.851	2.049	1.214	0.261	2.576	1.745	0.603	2.898	2.363	1.439
		w/o stge	0.226	-0.364	-0.385	0.230	-0.142	-0.295	0.248	-0.245	-0.323	0.265	-0.179	-0.273	-0.050	-0.420	-0.524
	4	w/stge	3.129	1.719	1.194	2.786	1.422	1.107	3.095	0.992	-0.191	3.682	2.419	1.950	3.925	2.498	3.853
		w/o stge	-0.095	-0.251	-0.150	-0.131	-0.123	-0.091	-0.018	-0.275	-0.119	0.002	-0.268	-0.410	-0.087	-0.257	-0.288
	5	w/stge	2.220	1.420	0.970	1.810	1.600	1.220	2.160	1.230	0.610	2.630	1.650	0.520	2.940	2.410	1.260
		w/o stge	0.165	-0.090	-0.064	0.195	-0.319	-0.165	0.332	-0.403	-0.236	0.080	-0.320	-0.272	0.227	-0.236	-0.351

Table 4 Wind Velocity Averages

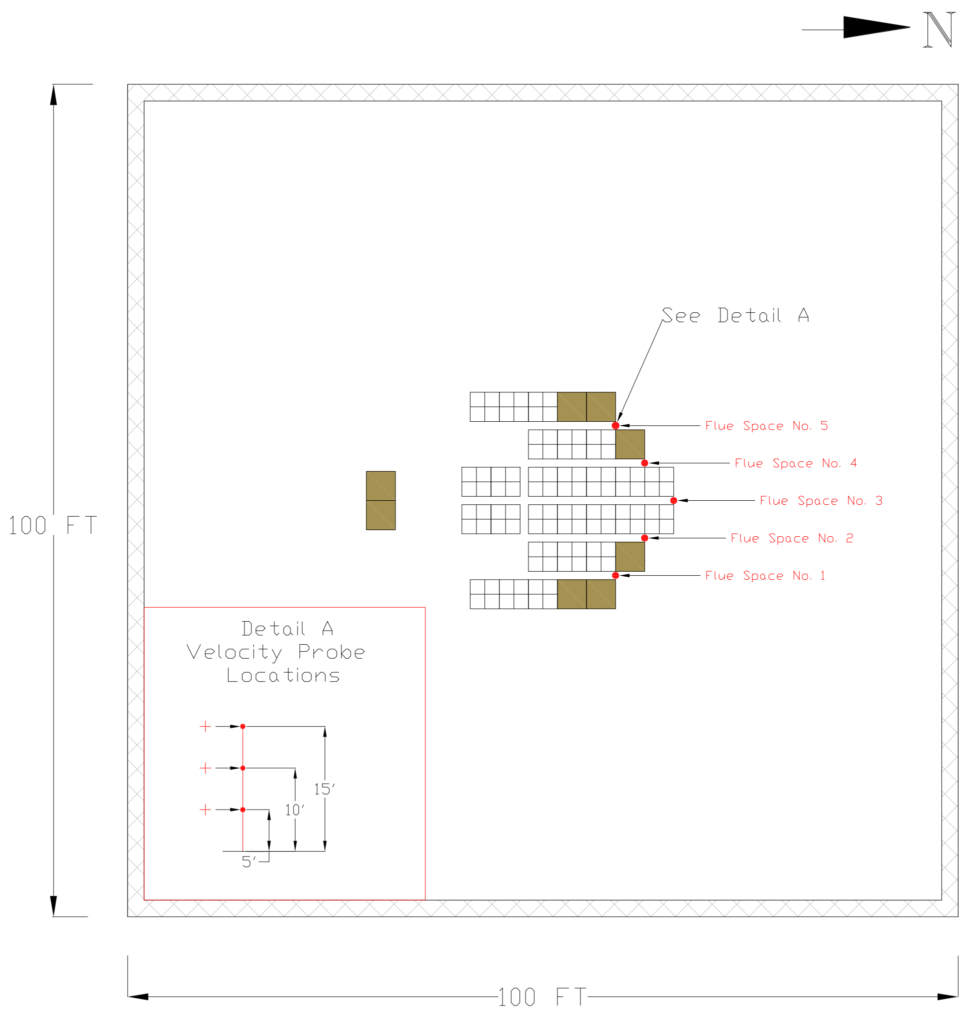


Figure 33 Velocity Probe General Detail

4.2 HVLS Fan Photos

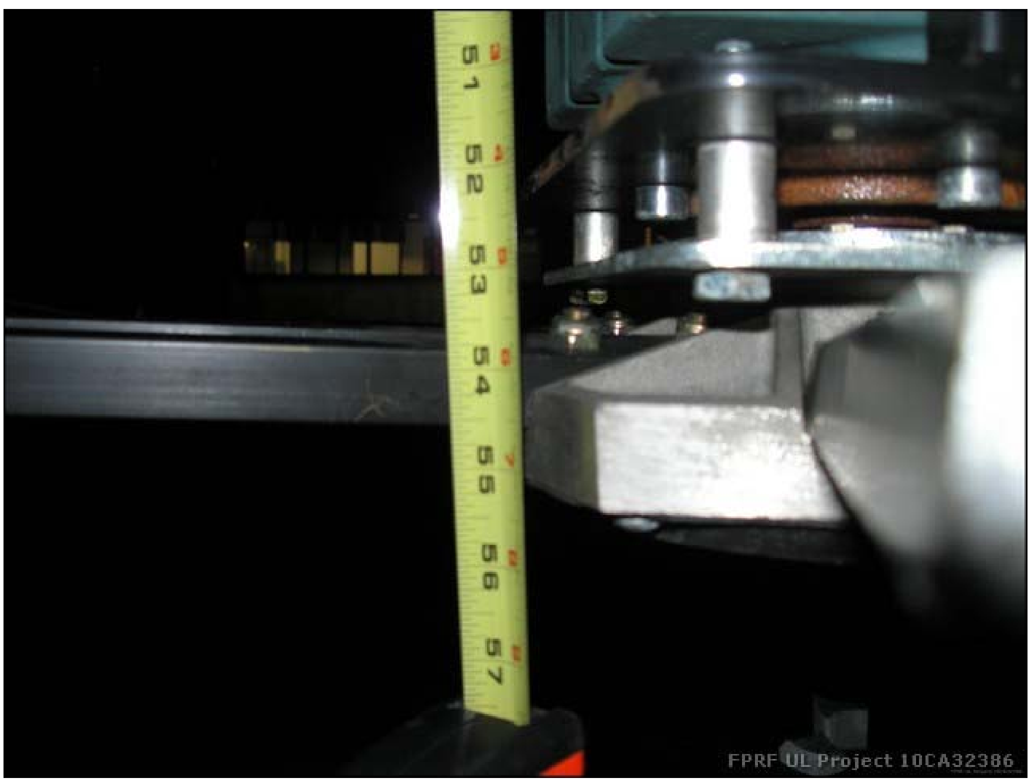


Figure 34 HVLS Fan Installation

4.3 Test Photos

4.3.1 TEST 1

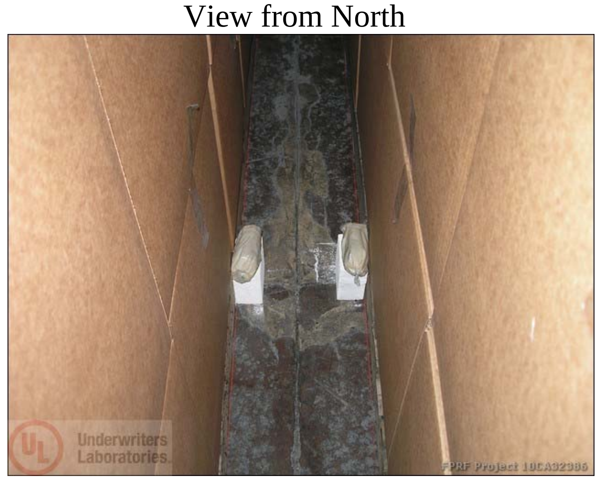
View from East

View from SE

View from NE

View from North

View from South



Igniters

Figure 35 Test 1 Photos

4.3.2 TEST 2

View from NE

View from SE

View from North

View from West

View from SW

Igniters

Figure 36 Test 2 Photos

4.3.3 TEST 3

View from South

View from SW

View from West

View from NW

View from North

Igniters

Figure 37 Test 3 Photos

4.3.4 TEST 4

View from SW

View from NE

View from West

View from North

View from East

Igniters

Figure 38 Test 4 Photos

4.3.5 TEST 5

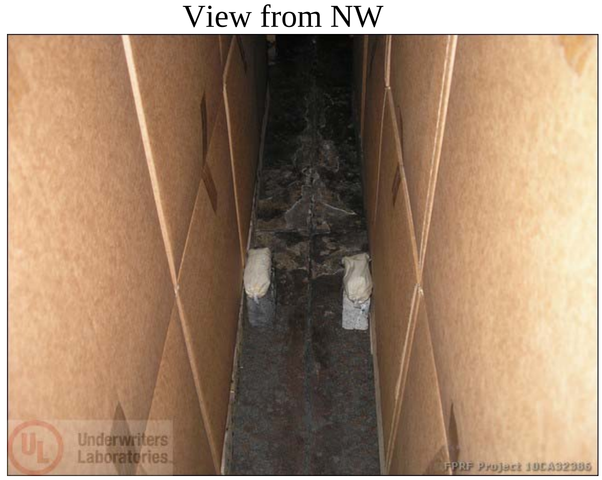
View from West

View from SW

View from South

View from NW

View from North



Igniters

Figure 39 Test 5 Photos

4.4 Test Results

4.4.1 TEST 1

The test was conducted for 30 minutes (30:00). A total of six (6) ceiling sprinklers operated during the 30-minute test period. The first sprinkler activated at one minute twenty-one seconds (01:21) after ignition and the last sprinkler operated at one minute forty-seven seconds (01:47) after ignition.

The fire in Test 1 was generally contained within the ignition array and did not spread to either end of the main array or to the adjacent targets. An estimated 25 pallets of commodity were damaged in this test. The maximum one-minute average steel beam temperature measured above ignition was 100ºF and the maximum one-minute average gas temperature measured above ignition was 131ºF.

The HVLS fan remained operational throughout and following the test.

Sprinkler operation times are presented in Figure 40, and a plan view of the extent of fire is presented in Figure 41. Post-test photos are presented in Figure 50. Tabulated test results are presented in Table 4. Temperature data vs. time charts are presented in Appendix A.

4.4.2 TEST 2

The test was conducted for 30 minutes (30:00). A total of six (6) ceiling sprinklers operated during the 30-minute test period. The first sprinkler activated at one minute five seconds (01:05) after ignition and the last sprinkler operated at one minute fifty-seven seconds (01:57) after ignition.

The fire in Test 2 was generally contained within the ignition array and did not spread to either end of the main array or to the adjacent targets. An estimated 23 pallets of commodity were damaged in this test. The maximum one-minute average steel beam temperature measured above ignition was 105ºF and the maximum one-minute average gas temperature measured above ignition was 154ºF.

The HVLS fan remained operational throughout and following the test.

Sprinkler operation times are presented in Figure 42, and a plan view of the extent of fire is presented in Figure 43. Post-test photos are presented in Figure 51. Tabulated test results are presented in Table 4. Temperature data vs. time charts are presented in Appendix B.

4.4.3 TEST 3

The test was conducted for 30 minutes (30:00). A total of six (6) ceiling sprinklers operated during the 30-minute test period. The first sprinkler activated at one minute thirty-six seconds (01:36) after ignition and the last sprinkler operated at one minute fifty-eight seconds (01:58) after ignition.

The fire in Test 3 was generally contained within the ignition array and did not spread to either end of the main array or to the adjacent targets. An estimated 26 pallets of commodity were damaged in this test. The maximum one-minute average steel beam temperature measured above ignition was 219ºF and the maximum one-minute average gas temperature measured above ignition was 1042ºF.

The HVLS fan was powered off at the time of VESDA alarm activation (1:36).

Sprinkler operation times are presented in Figure 44, and a plan view of the extent of fire is presented in Figure 45. Post-test photos are presented in Figure 52. Tabulated test results are presented in Table 4. Temperature data vs. time charts are presented in Appendix C.

4.4.4 TEST 4

The test was conducted for 30 minutes (30:00). A total of seven (7) ceiling sprinklers operated during the 30-minute test period. The first sprinkler activated at two minutes eight seconds (02:08) after ignition and the last sprinkler operated at three minutes twenty-eight seconds (03:28) after ignition.

The fire in Test 4 was generally contained within the ignition array and did not spread to either end of the main array or to the adjacent targets. An estimated 15 pallets of commodity were damaged in this test. The maximum one-minute average steel beam temperature measured above ignition was 122ºF and the maximum one-minute average gas temperature measured above ignition was 360ºF.

The HVLS fan was powered off at the time of the first ionization smoke detector activation (1:43). The VESDA “FIRE 1” alarmed at 1:50. At approximately 2:00 after ignition, the aluminum fan blades failed at the point where they mate with the fan hub.

Sprinkler operation times are presented in Figure 46, and a plan view of the extent of fire is presented in Figure 47. Post-test photos are presented in Figure 50. Tabulated test results are presented in Table 4. Temperature data vs. time charts are presented in Appendix D.

4.4.5 TEST 5

The test was conducted for 30 minutes (30:00). A total of six (20) ceiling sprinklers operated during the 30-minute test period. The first sprinkler activated at one minute thirteen seconds (01:13) after ignition and the last sprinkler operated at three minutes one second (03:01) after ignition.

The fire in Test 5 was generally contained within the ignition array and did not spread to either end of the main array or to the adjacent targets. An estimated 32 pallets of commodity were damaged in this test. The maximum one-minute average steel beam temperature measured above ignition was 327ºF and the maximum one-minute average gas temperature measured above ignition was 1287ºF.

The HVLS fan was powered off at the time of the first sprinkler operation plus 90 seconds to simulate a waterflow alarm delay (2:43).

Data was collected for both spot detector and VESDA activation times, as follows:

1st Ionization Detector	00:51
VESDA LED's 1-10	01:09
VESDA Alert	01:16
VESDA Action	01:16
VESDA Fire 1	01:19
VESDA Fire 2	01:28

Sprinkler operation times are presented in Figure 48, and a plan view of the extent of fire is presented in Figure 49. Post-test photos are presented in Figure 50. Tabulated test results are presented in Table 4. Temperature data vs. time charts are presented in Appendix E.

FIRE TEST	Test 4 UL-1 (9.15.10)	Test 5 UL-2 (9.17.10)	Test 6 UL-3 (9.21.10)	Test 7 UL-4 (9.23.10)	Test 8 UL-5 (9.27.10)
Parameters					
Location of Test	U.L.	U.L.	U.L.	U.L.	U.L.
Storage Type	Palletized Open Array	Palletized Open Array	Palletized Open Array	Palletized Open Array	Palletized Open Array
Commodity Type	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic	Cartoned, Unexpanded Group A Plastic
Nominal Storage Height (ft)	15	15	15	15	15
Nominal Ceiling Height (ft)	40	40	25	25	25
Nominal Clearance (ft)	25	25	10	10	10
Aisle Width (in.)	N/A	N/A	N/A	N/A	N/A
Longitudinal/Transverse Flue (in.)	12	12	12	12	12
Ignition Location	Between 4 Sprinklers (centered)	Between 4 Sprinklers (centered)	Between 4 Sprinklers (centered)	Between 4 Sprinklers (centered)	Between 4 Sprinklers (centered)
Ignitor Detail	2 Full Ignitors	2 Full Ignitors	2 Full Ignitors	2 Full Ignitors	2 Full Ignitors
Sprinkler Type/Temperature Rating (°F)	ESFR/165	ESFR/165	CMDA/286	CMDA/286	CMDA/286
Sprinkler Orientation	Pendent	Pendent	Upright	Upright	Upright
Sprinkler Sensitivity	Fast Response	Fast Response	Std. Response	Std. Response	Std. Response
Sprinkler Make/Model Number	Tyco/ESFR-1	Tyco/ESFR-1	Tyco/ELO-231-B	Tyco/ELO-231-B	Tyco/ELO-231-B
Deflector to Ceiling (in.)	14	14	3	3	3
Nominal Sprinkler Discharge Coefficient K ($gpm/psi^{1/2}$)	14	14	11.2	11.2	11.2
Density/Nominal Sprinkler Discharge Pressure (psi)	75	75	0.60 gpm/sq ft	0.60 gpm/sq ft	0.60 gpm/sq ft
Sprinkler Spacing (ft x ft)	10 x 10	10 x 10	8 x 10	8 x 10	8 x 10
Fan Size (ft)	24	24	24	24	24
Fan Location (centered between 4 sprinklers)	Fan Tip 2 ft Beyond Ignition	Hub Above Ignition	Fan Tip 3 ft Beyond Ignition	Hub 1 ft West of Ignition	Fan Tip 3 ft Beyond Ignition
Fan Distance Below Ceiling (in.)	54.5	54.5	54.5	54.5	54.5
HVLS Fan Speed (rpm)	63	63	63	63	63
HVLS Fan Operation	On (no shutdown)	On (no shutdown)	Off at Smoke/Particle Detection Operation(1:36)	Off at Smoke Detection Operation	Off at Waterflow (90 second delay)
HVLS Fan Manufacturer	MacroAir	MacroAir	MacroAir	MacroAir	MacroAir
HVLS Fan Model Name	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL	MaxAir Whisperfoil XL
HVLS Fan Model Number	MA24XL2006	MA24XL2007	MA24XL2008	MA24XL2009	MA24XL2010
HVLS Fan Blade Geometry	Whisperfoil XL	Whisperfoil XL	Whisperfoil XL	Whisperfoil XL	Whisperfoil XL
HVLS Fan Number of Blades	6	6	6	6	6
Results					
Length of Test (hr:min:s)	0:30:00	0:30:00	0:30:00	0:30:00	0:30:00
First Ceiling Sprinkler Operation (min:s)	1:21	1:05	1:36	2:08	1:13
Last Ceiling Sprinkler Operation (min:s)	1:47	1:57	1:58	3:28	3:01
Number of Operated Ceiling Sprinklers	6	6	6	7	20
Peak Gas Temperature at Ceiling Above Ignition (°F)	207	181	1468	504	1506
Maximum 1 Minute Average Gas Temperature at Ceiling Above Ignition (°F)	131	154	1042	360	1287
Peak Steel Temperature at Ceiling Above Ignition (°F)	102	118	244	122	415
Maximum 1 Minute Average Steel Temperature Above Ignition (°F)	100	105	219	122	327
Fire Spread Across Aisle	NO	NO	NO	NO	NO
Fire spread to the Ends of the Array	NO	NO	NO	NO	NO
Fuel Consumed (number of pallets)	25	23	26	15	32
Test Outcome (Pass/Fail)	PASS	PASS	PASS	PASS	
COMMENTS			No delay in fan shutdown after detection operation	Fan blades failed (bent) just after shutdown	Replacement fan used (same model)

Table 5 Summary of Test Parameters and Results

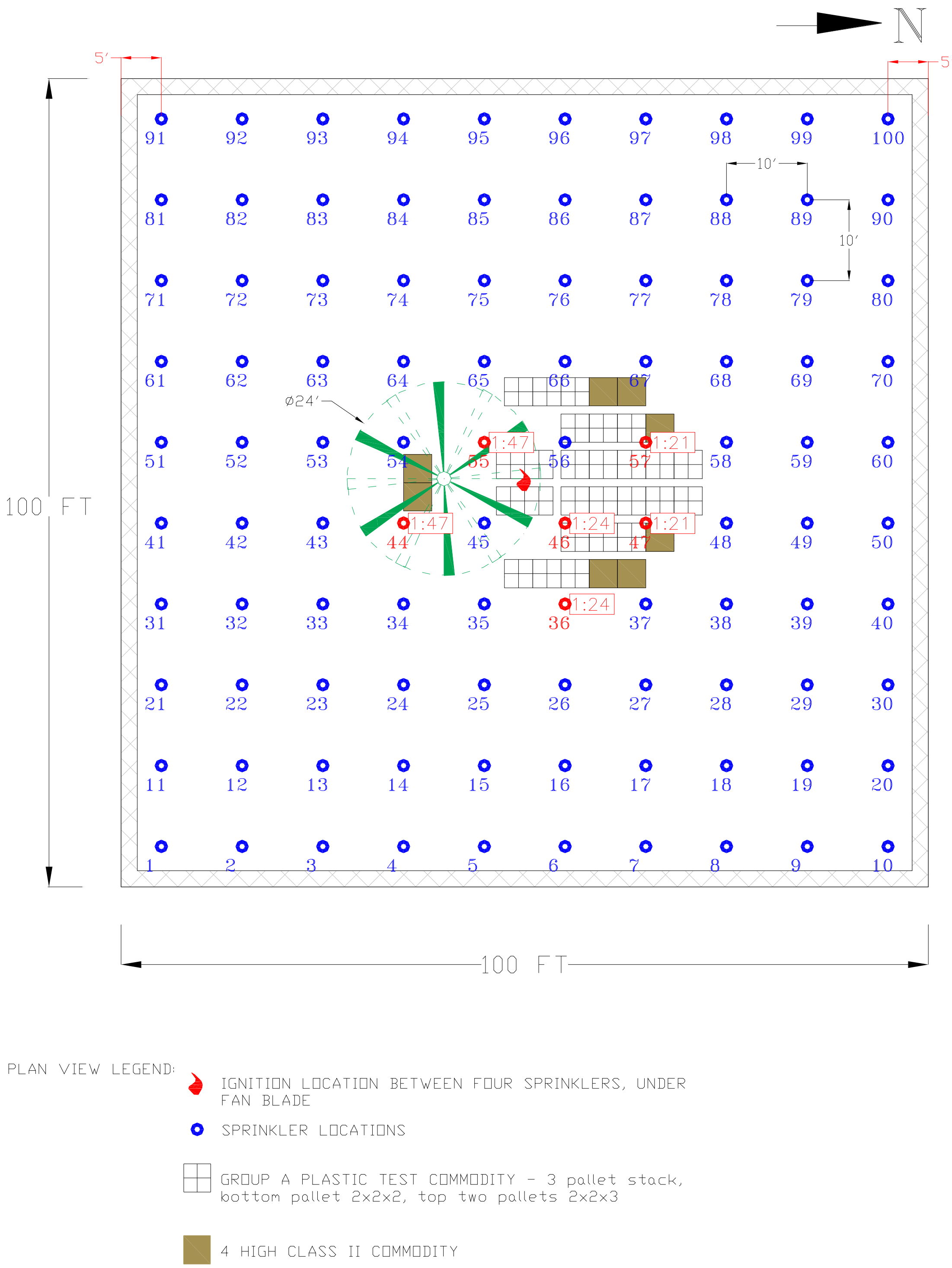


Figure 40 Sprinkler Operations – Test 1

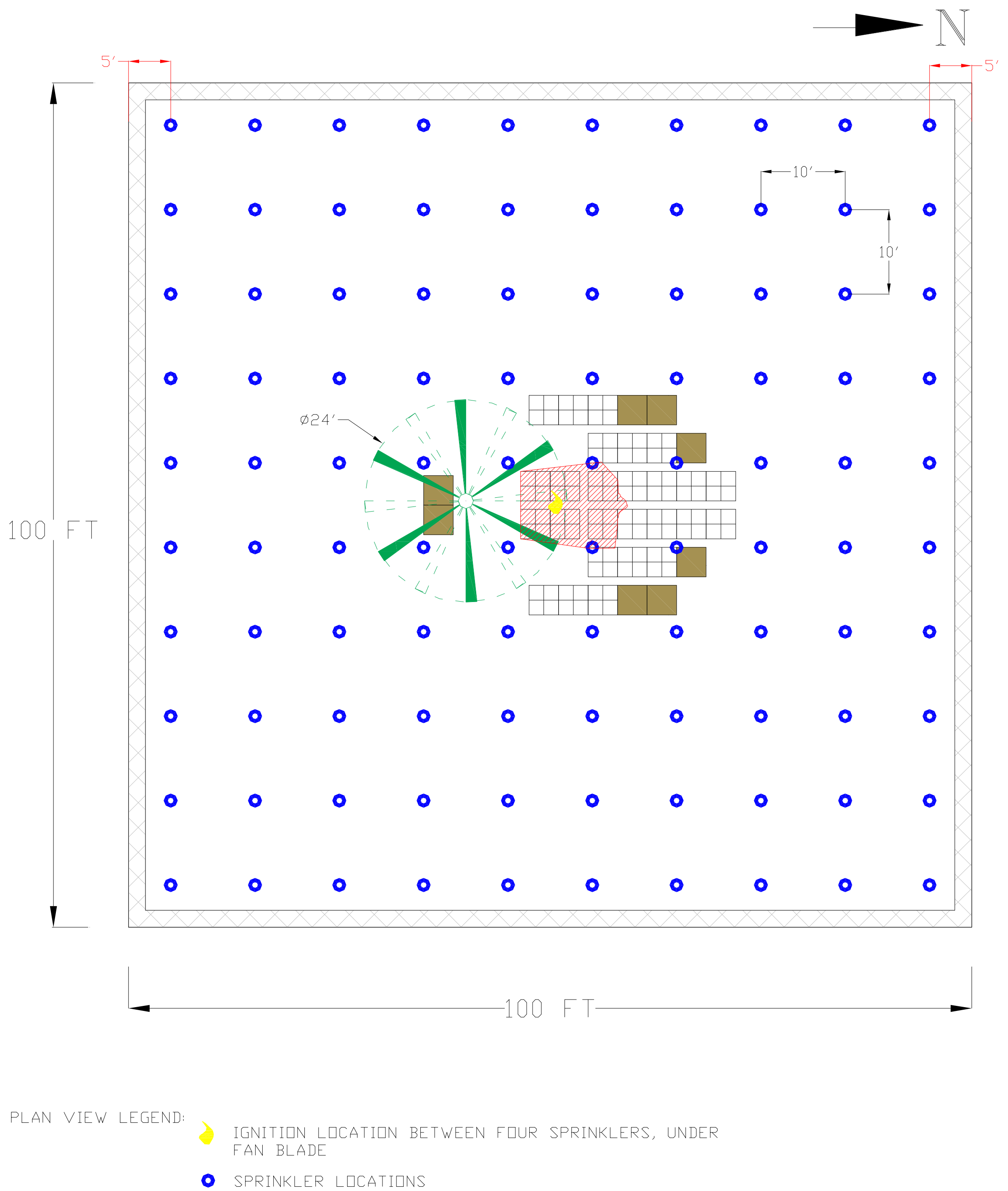


Figure 41 Damage Assessment Plan View – Test 1

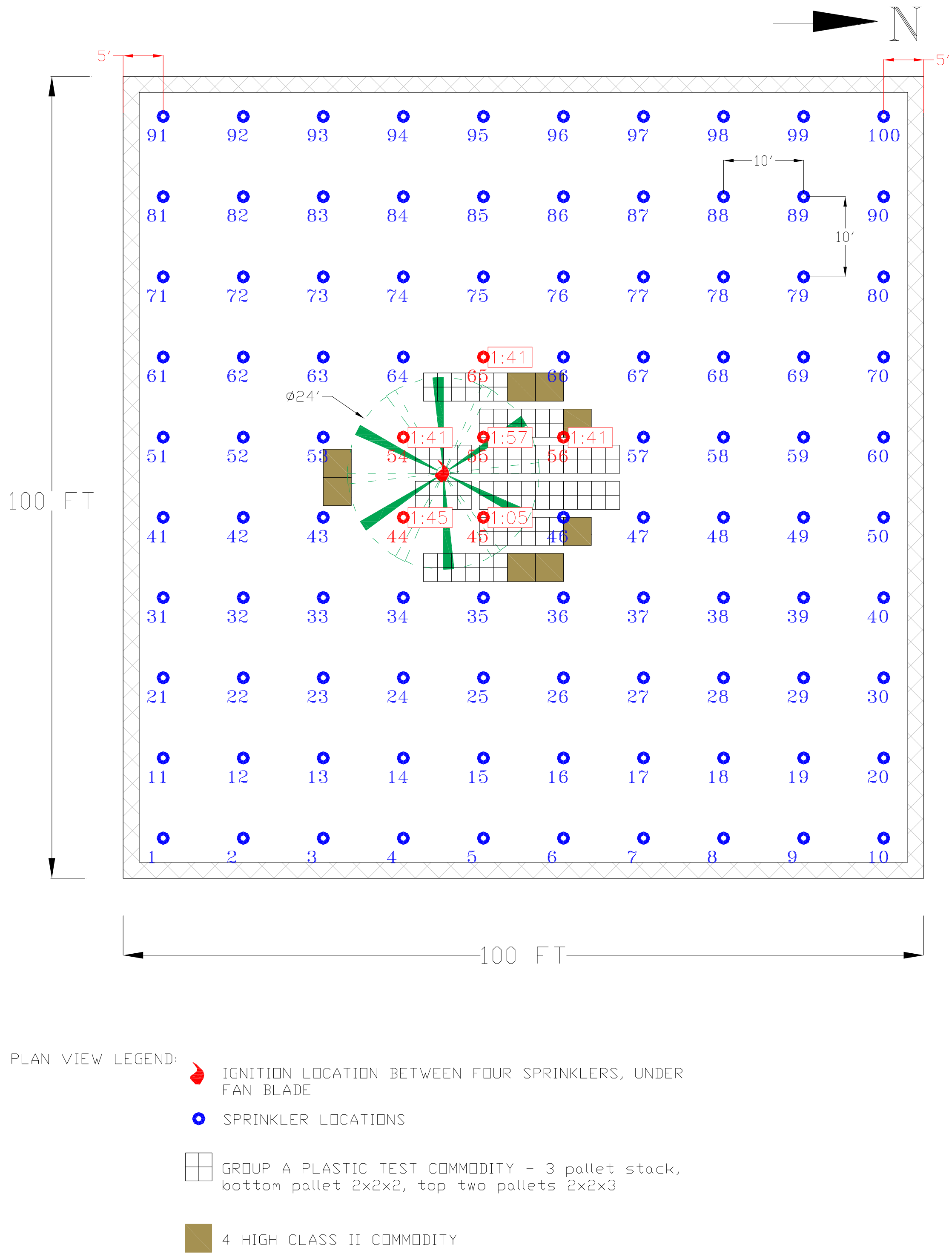


Figure 42 Sprinkler Operations – Test 2

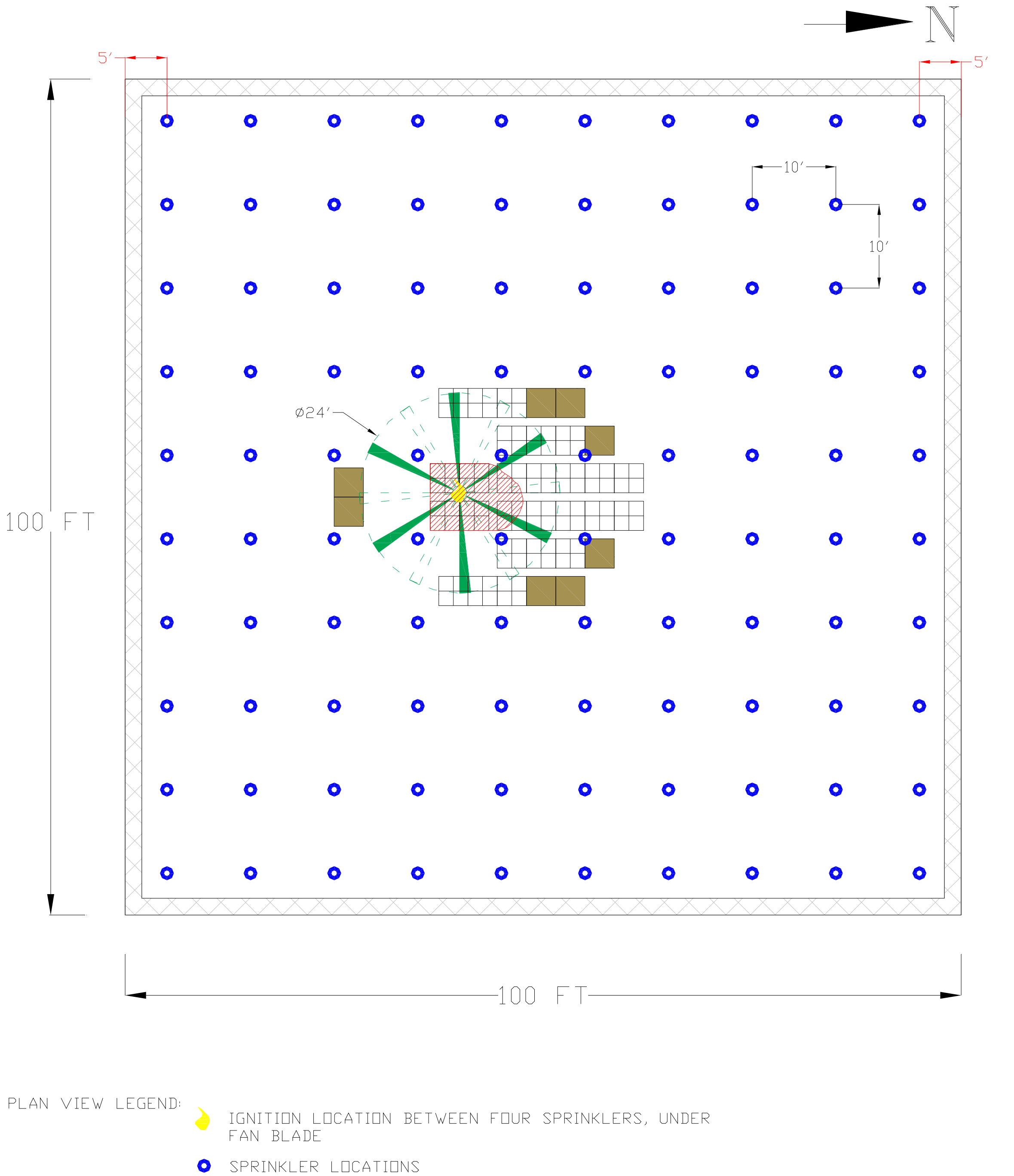


Figure 43 Damage Assessment Plan View – Test 2

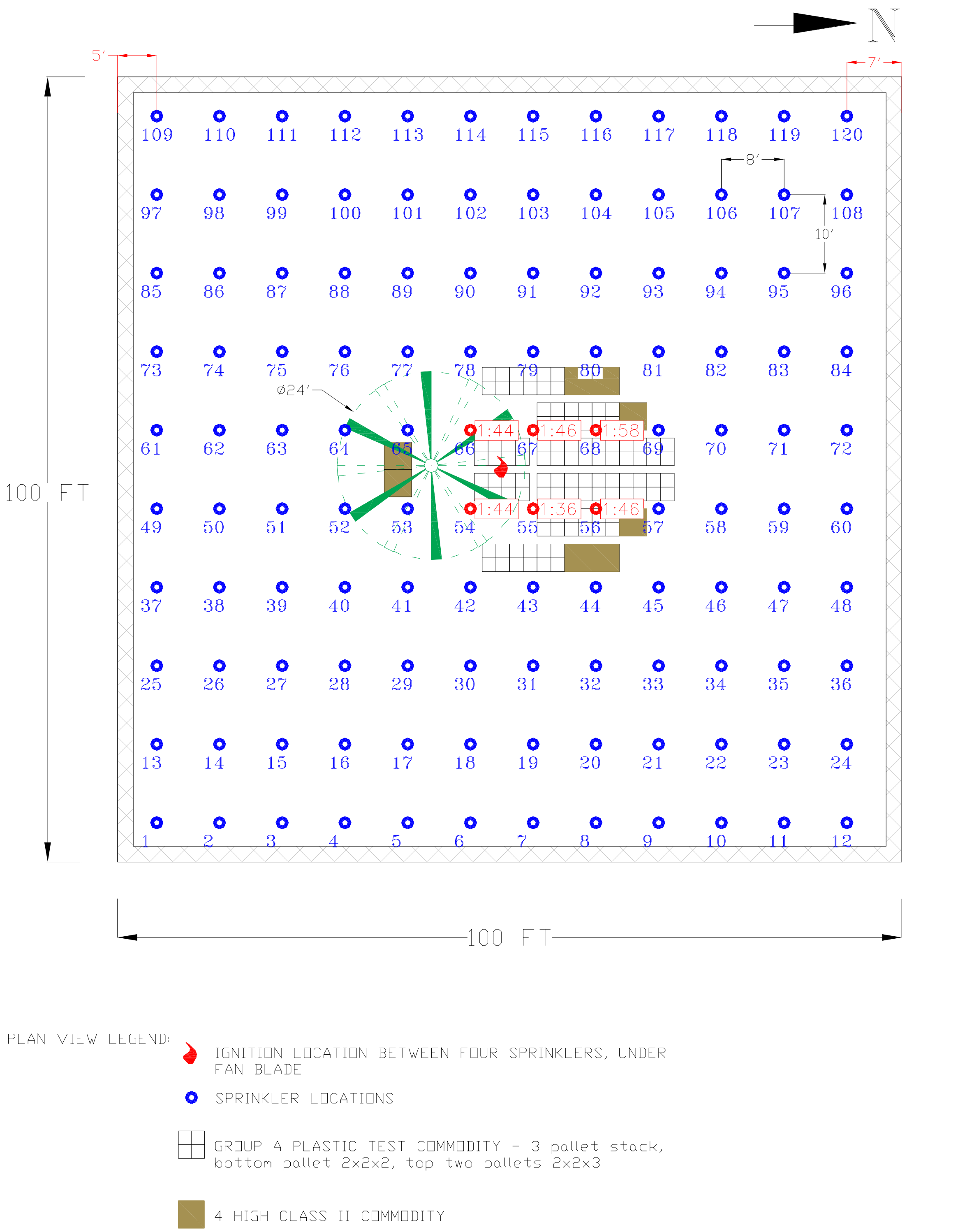


Figure 44 Sprinkler Operations – Test 3

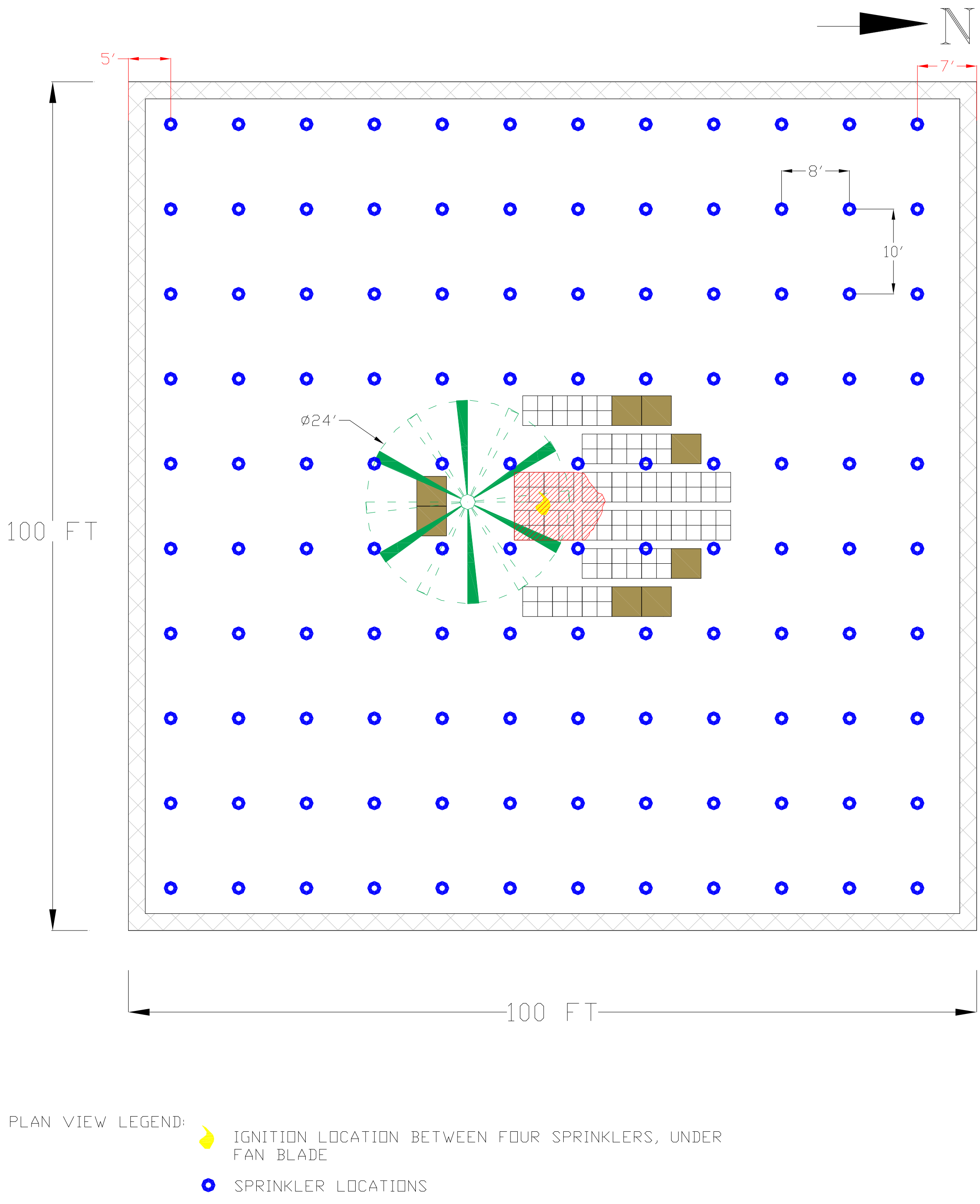


Figure 45 Damage Assessment Plan View – Test 3

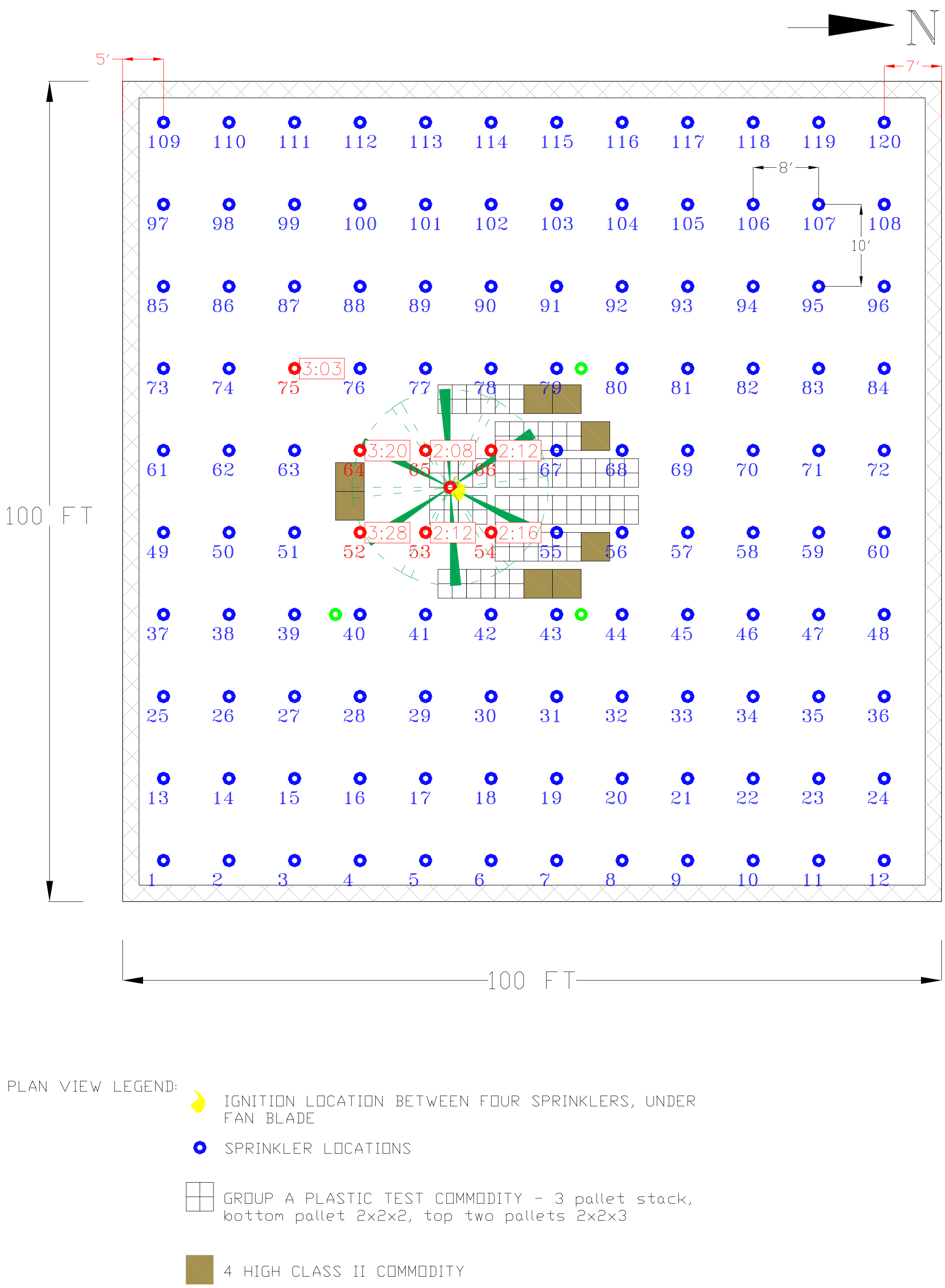


Figure 46 Sprinkler Operations – Test 4

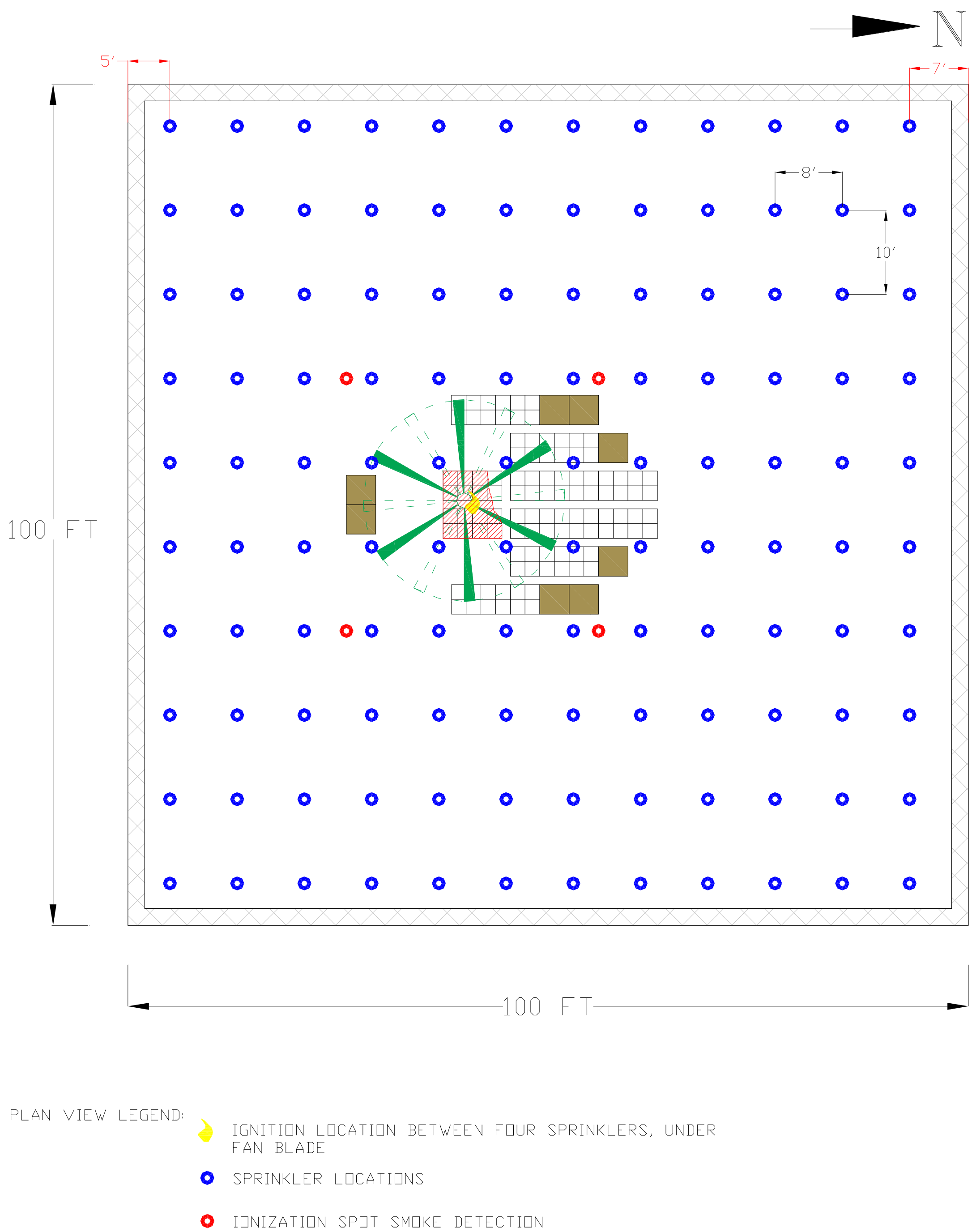
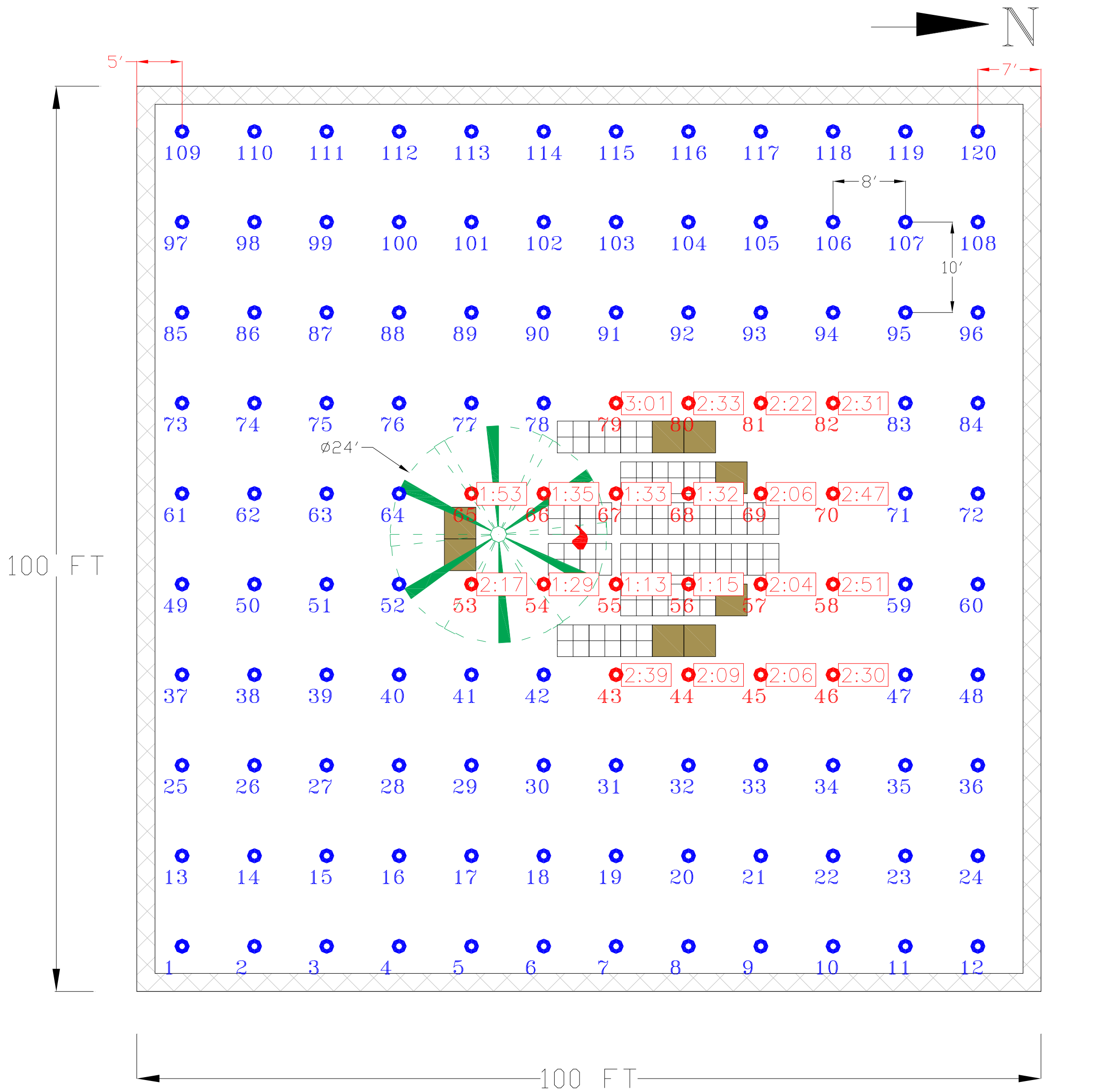


Figure 47 Damage Assessment Plan View – Test 4



PLAN VIEW LEGEND:

IGNITION LOCATION BETWEEN FOUR SPRINKLERS, UNDER FAN BLADE

SPRINKLER LOCATIONS

GROUP A PLASTIC TEST COMMODITY - 3 pallet stack, bottom pallet 2x2x2, top two pallets 2x2x3

4 HIGH CLASS II COMMODITY

Figure 48 Sprinkler Operations – Test 5

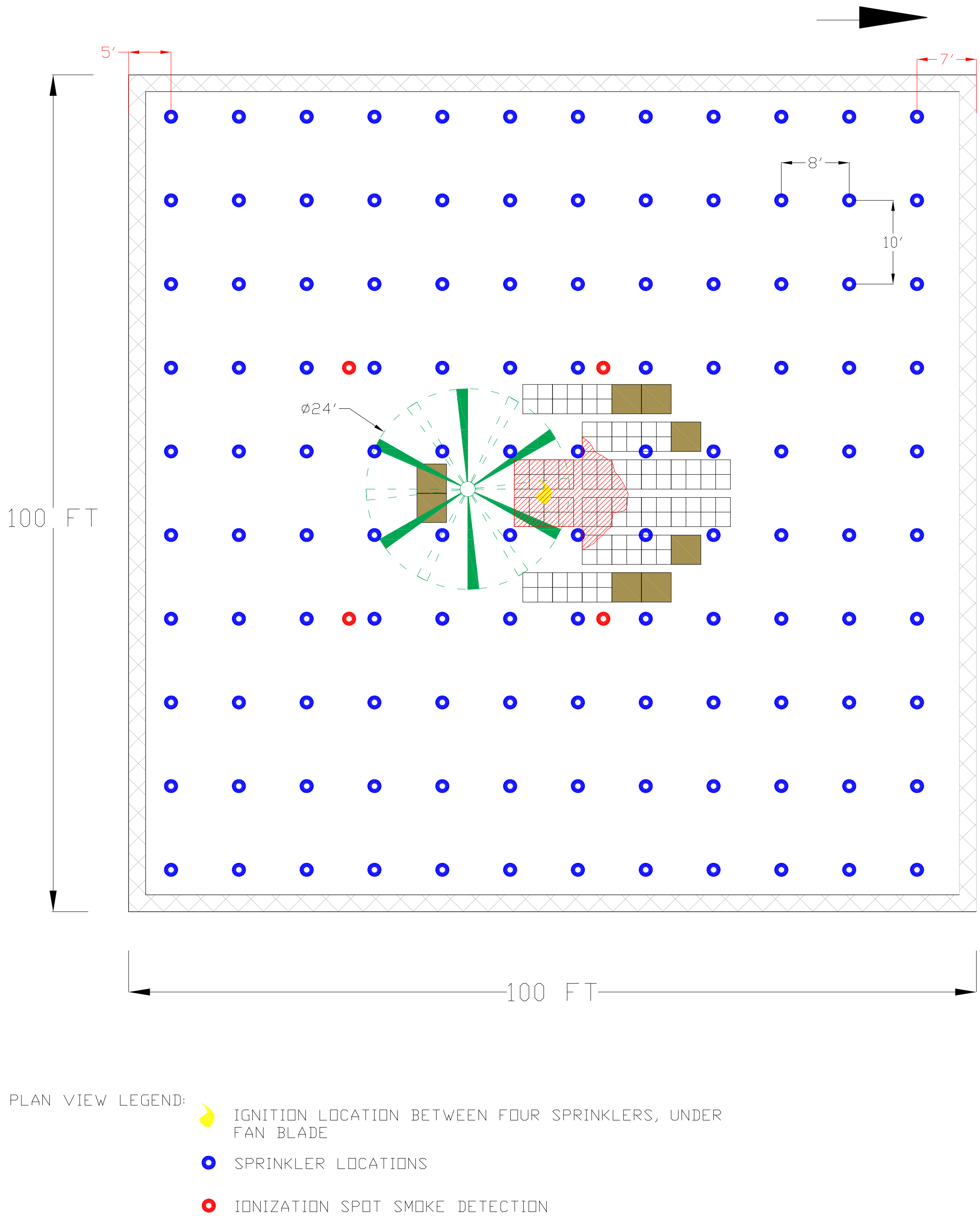


Figure 49 Damage Assessment Plan View – Test 5

4.5 Post-Test Photos

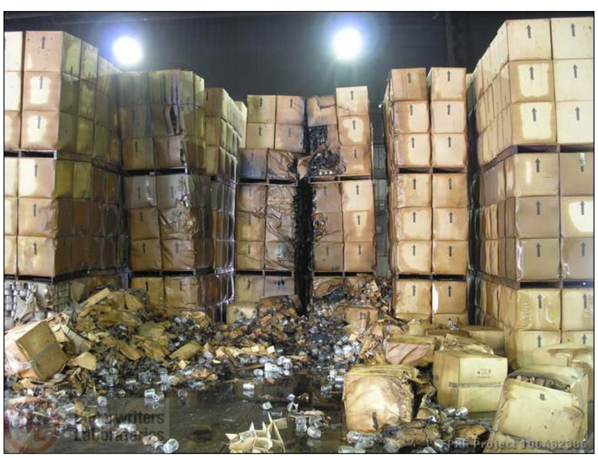
4.5.1 TEST 1

View from North

View from South

View from NE

View from West



View from South

View above Ignition

Figure 50 Post Test Photos – Test 1

4.5.2 TEST 2

View from South

View from North

View from East

View from West

View from SE balcony

View from SE

Figure 51 Post Test Photos – Test 2

4.5.3 TEST 3

View from South

View from North

View from East

View from West

View from South

View from SE balcony

Figure 52 Post Test Photos – Test 3

4.5.4 TEST 4

View from North

View from NE

View from West

View from South

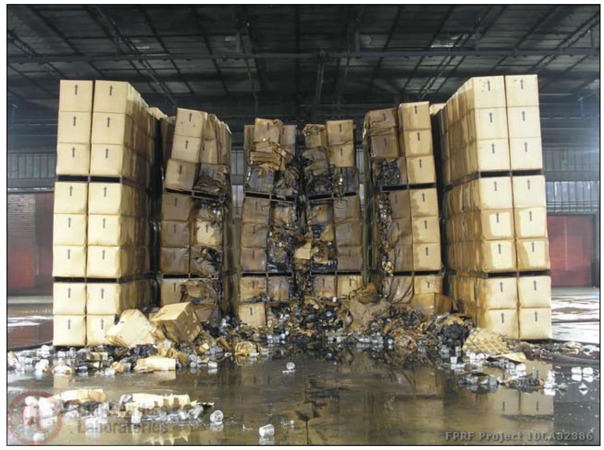
View from SE balcony

VESDA Control Panel
(in full alarm after 01:28)

Figure 53 Post Test Photos – Test 4

4.5.5 TEST 5

View from South



View from North

View from NE

View from West

View from SE balcony

View from SE balcony

Figure 54 Post Test Photos – Test 5

5 SUMMARY

A series of five (5) large-scale fire tests were conducted to develop data regarding the level of protection provided for a palletized storage arrangement of Group A plastic commodity by ceiling sprinklers with an operating High Volume Low Speed (HVLS) 6-blade fan mounted 54.5-in below the ceiling. Two (2) of the tests were conducted with nominal K-14.0 gpm/psi$^{1/2}$ pendent ESFR sprinklers, and three (3) of the tests were conducted with nominal K-11.2 gpm/psi$^{1/2}$ upright control mode sprinklers. The palletized storage arrangement of cartoned, unexpanded Group A plastic test commodity to a nominal height of 15-ft was positioned under a 40-ft ceiling for the ESFR tests, and a 30-ft ceiling for the control mode sprinkler tests.

Tests 1 and 2 were conducted with 165°F temperature rated pendent ESFR ceiling sprinklers installed on 10 by 10-ft. spacing with the deflectors positioned 14-in. below the ceiling. A target array was positioned across an 8 ft. aisle space to the south of the main array. For both tests, the ceiling sprinkler system was supplied with water resulting in a nominal sprinkler discharge pressure of 75 psi.

Tests 3, 4 and 5 were conducted with 286°F temperature rated standard response upright ceiling sprinklers installed on 8 by 10-ft. spacing with the deflectors positioned 3-in. below the ceiling. A target array was positioned across an 8 ft aisle space to the south of the main array. For these three tests, the ceiling sprinkler system was supplied with water resulting in a nominal sprinkler discharge density of 0.60 gpm/ft^2. These tests also incorporated a simulated interlocking mechanism, including ionization detectors mounted at the ceiling, as well as a VESDA smoke detection system.

Tests 1, 3 and 5 were conducted with the main ignition scenario located between four sprinklers (2 ft in from the fan tip in Test 1 and 3 ft in from the fan tip in Tests 3 and 5). The center of 24-ft HVLS fan located offset from the main array 10-ft south of the ignition location. Each test was conducted for 30 minutes (30:00), and a total of six (Test 1), six (Test 3) and twenty (Test 5) sprinklers operated during the test period. The fire in each test was centered around the center bay above the ignition location and did not spread to either end of the main array or to the adjacent target array.

Tests 2 and 4 were conducted with the main ignition scenario located between four sprinklers (beneath the fan hub in Test 2 and 1 ft offset to the East in Test 4). Both tests were conducted for 30 minutes (30:00), and a total of six (Test 2) and seven (Test 4) sprinklers operated during the test period. The fire in each test was centered around the center bay above the ignition location and did not spread to either end of the main array or to the adjacent target array.

A summary of the parameters and results is presented in Table 4.

Report by:

Christopher Gates
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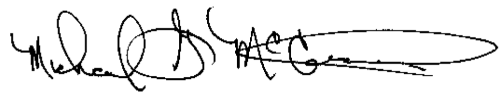
Reviewed by:

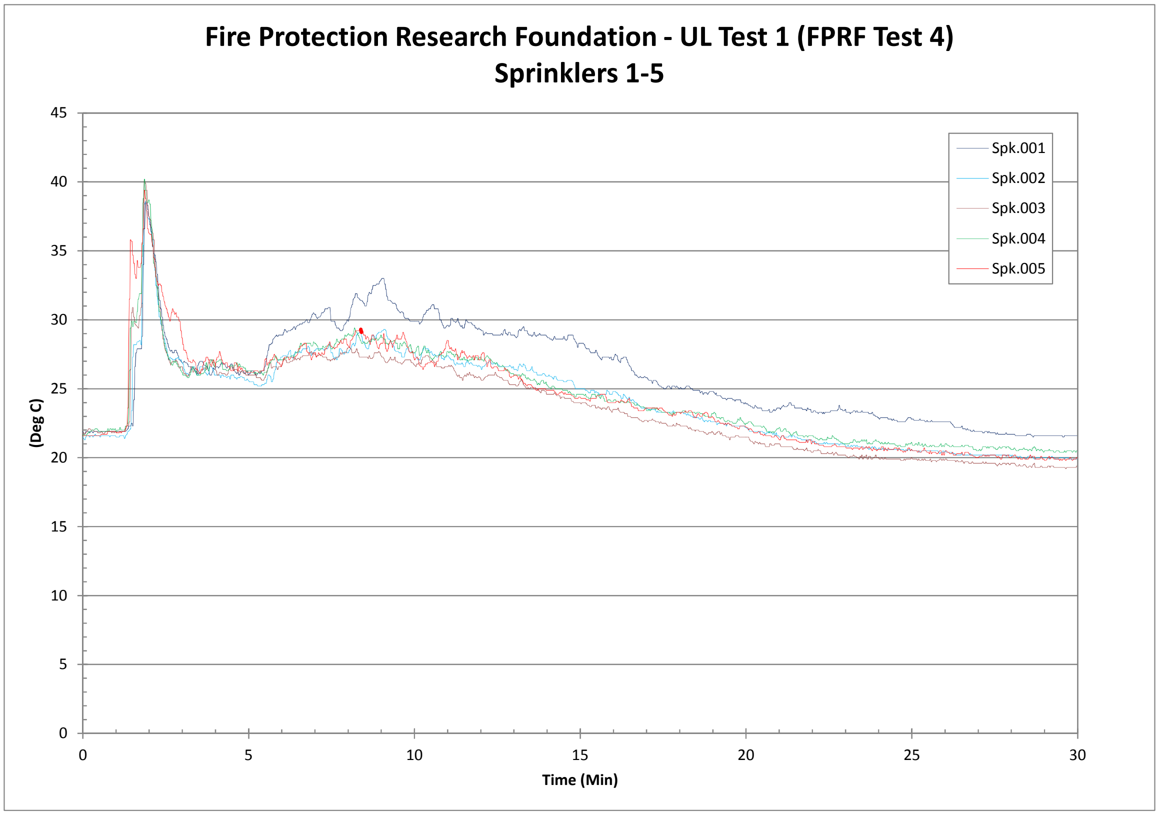


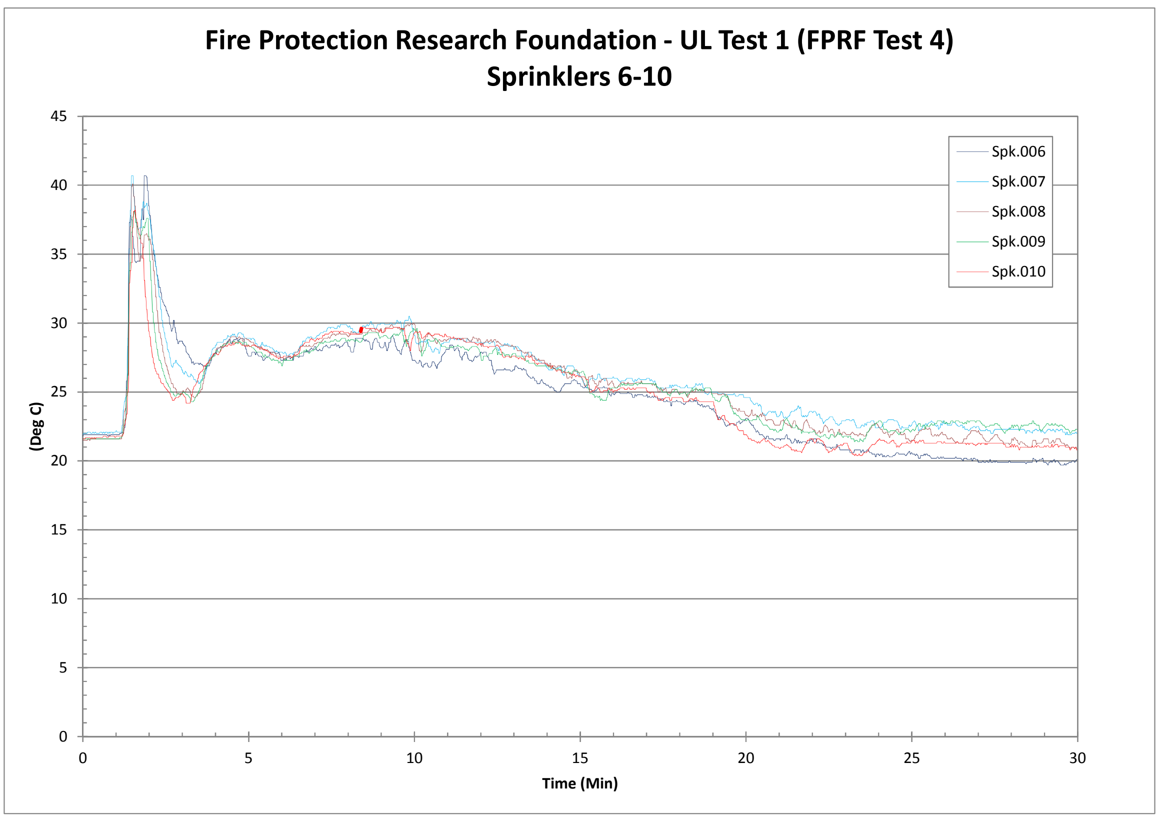
Michael McCormick
Staff Engineering Associate
Tel: 847-664-3303
Fax: 847-313-3303

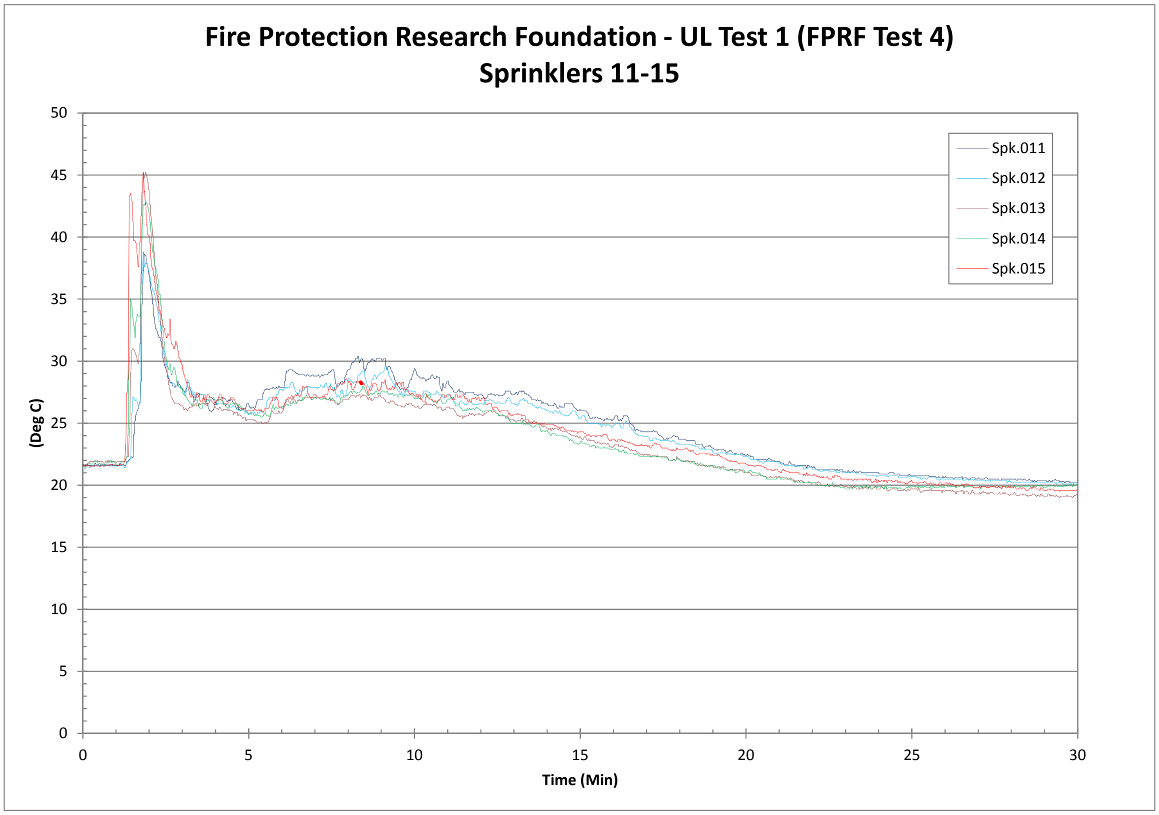
APPENDIX A

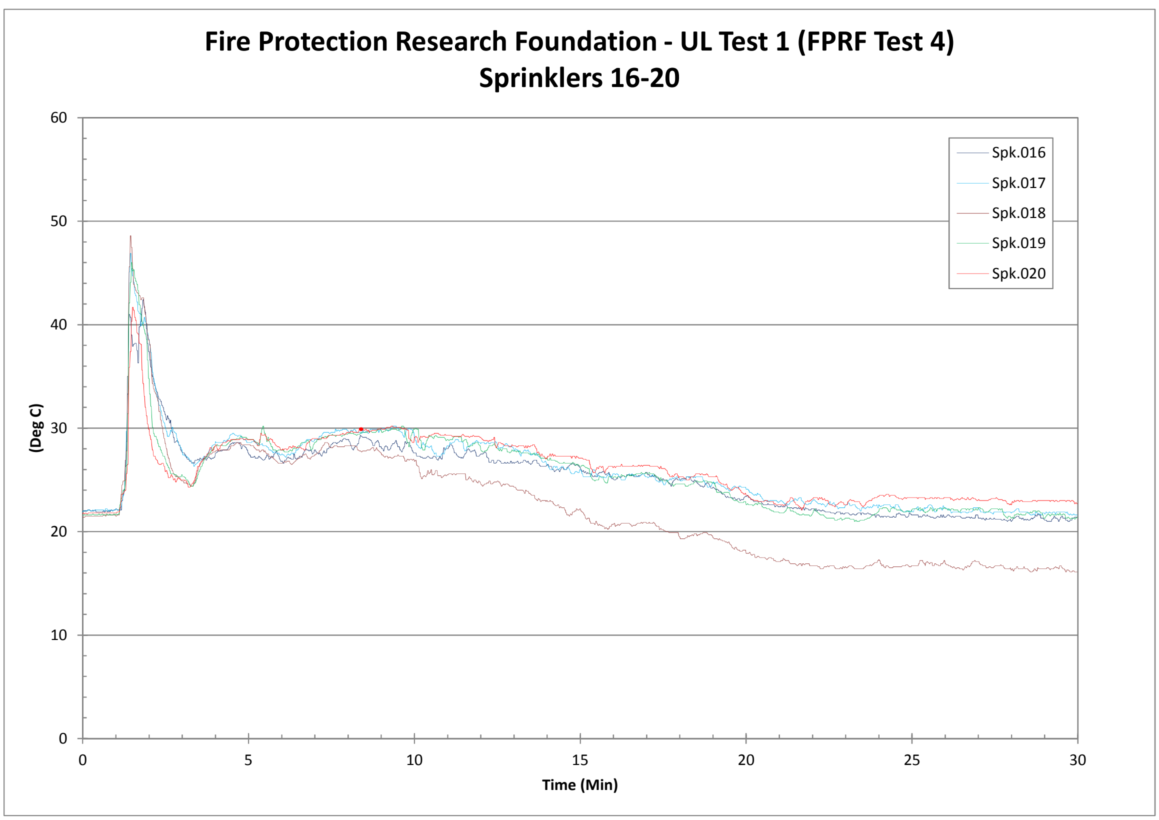
Graphical Presentation of

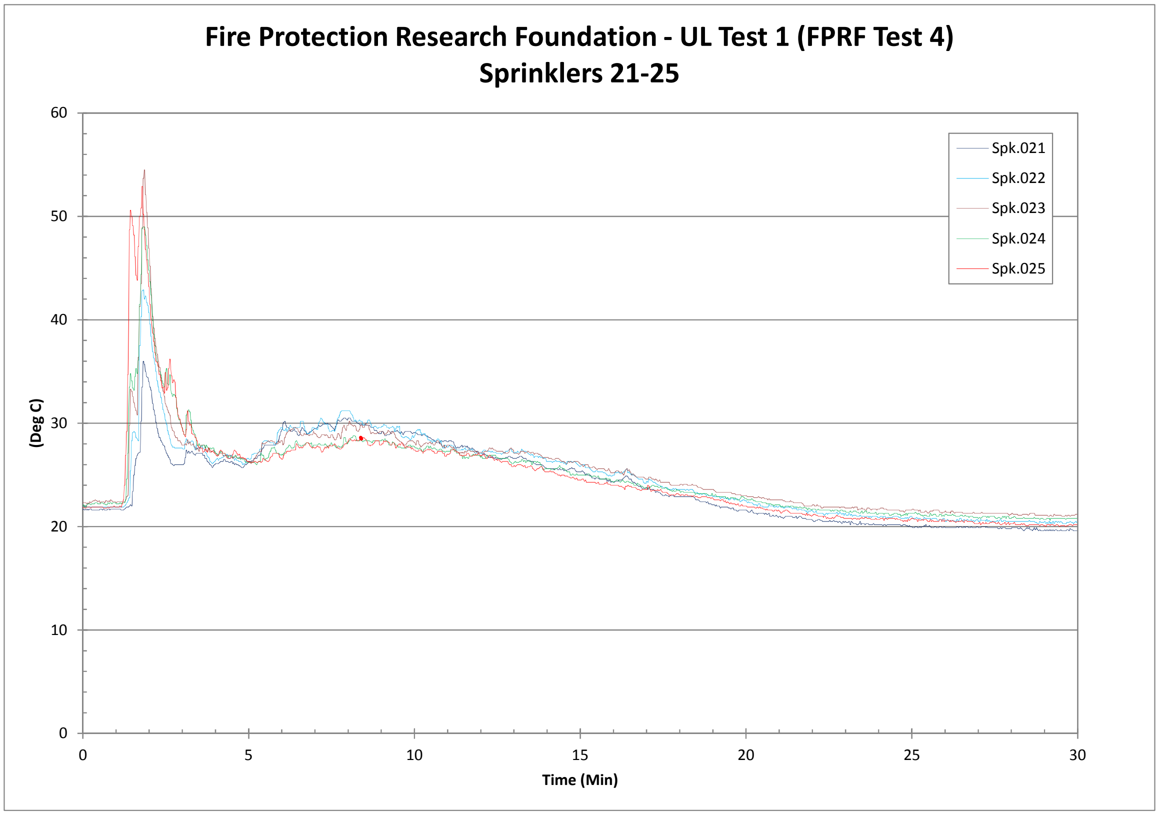
Gas Temperatures, Steel Temperatures, System Waterflow and Velocities - Test 1

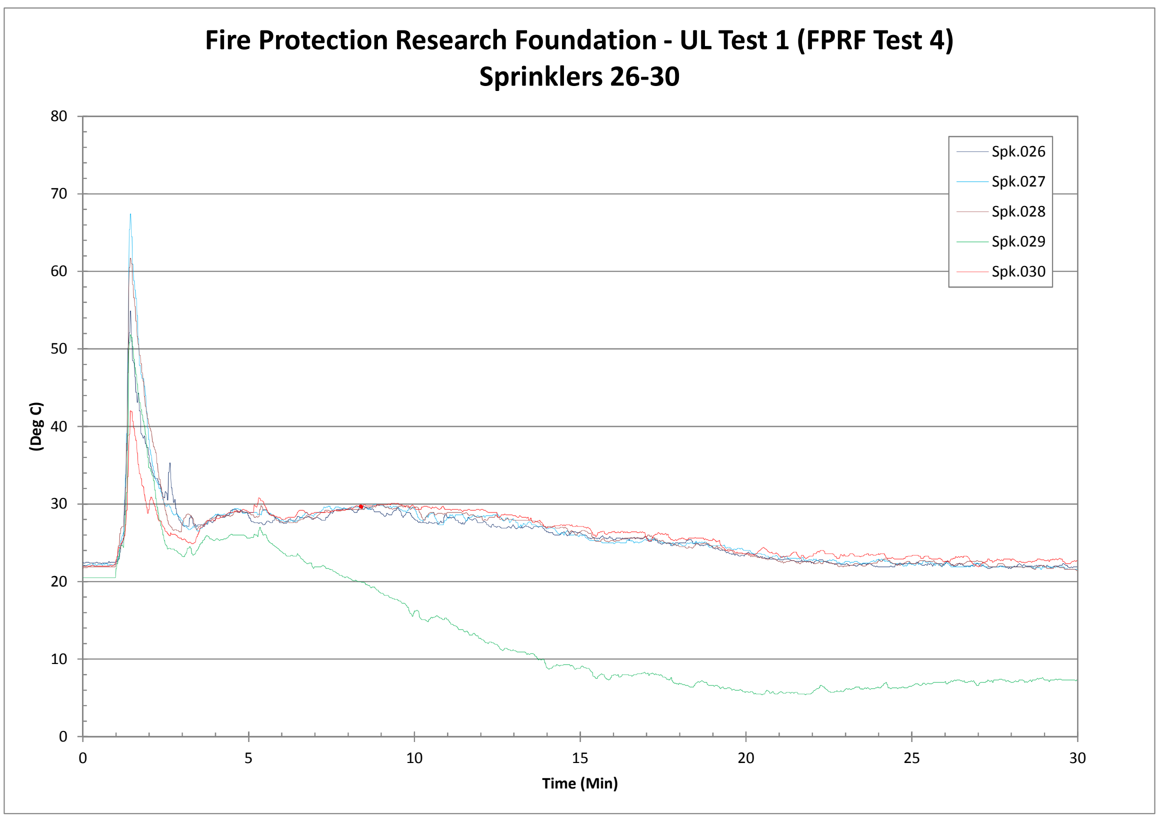

Fire Protection Research Foundation - UL Test 1 (FPRF Test 4)
Sprinklers 1-5
(Deg C)
Time (Min)
Spk.001
Spk.002
Spk.003
Spk.004
Spk.005
0
5
10
15
20
25
30
35
40
45
0
5
10
15
20
25
30

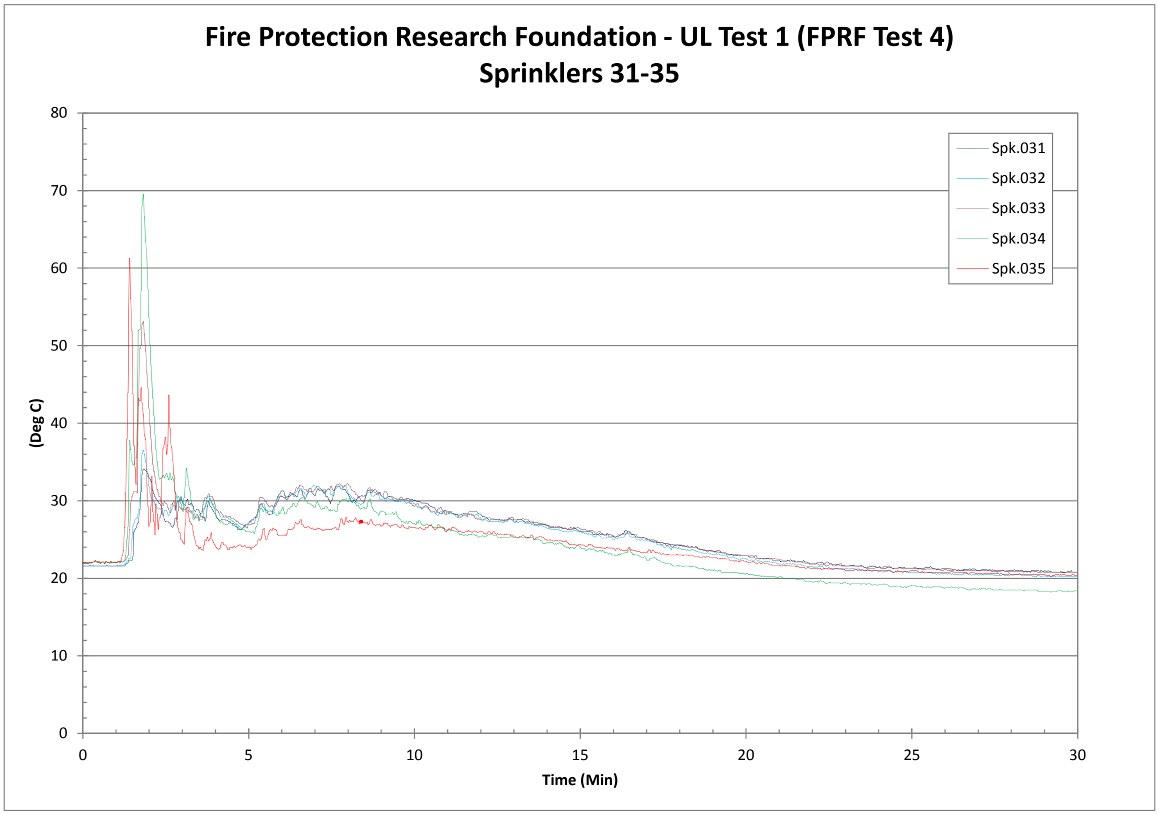

Fire Protection Research Foundation - UL Test 1 (FPRF Test 4)
Sprinklers 6-10
(Deg C)
Time (Min)
Spk.006
Spk.007
Spk.008
Spk.009
Spk.010
0
5
10
15
20
25
30
35
40
45
0
5
10
15
20
25
30

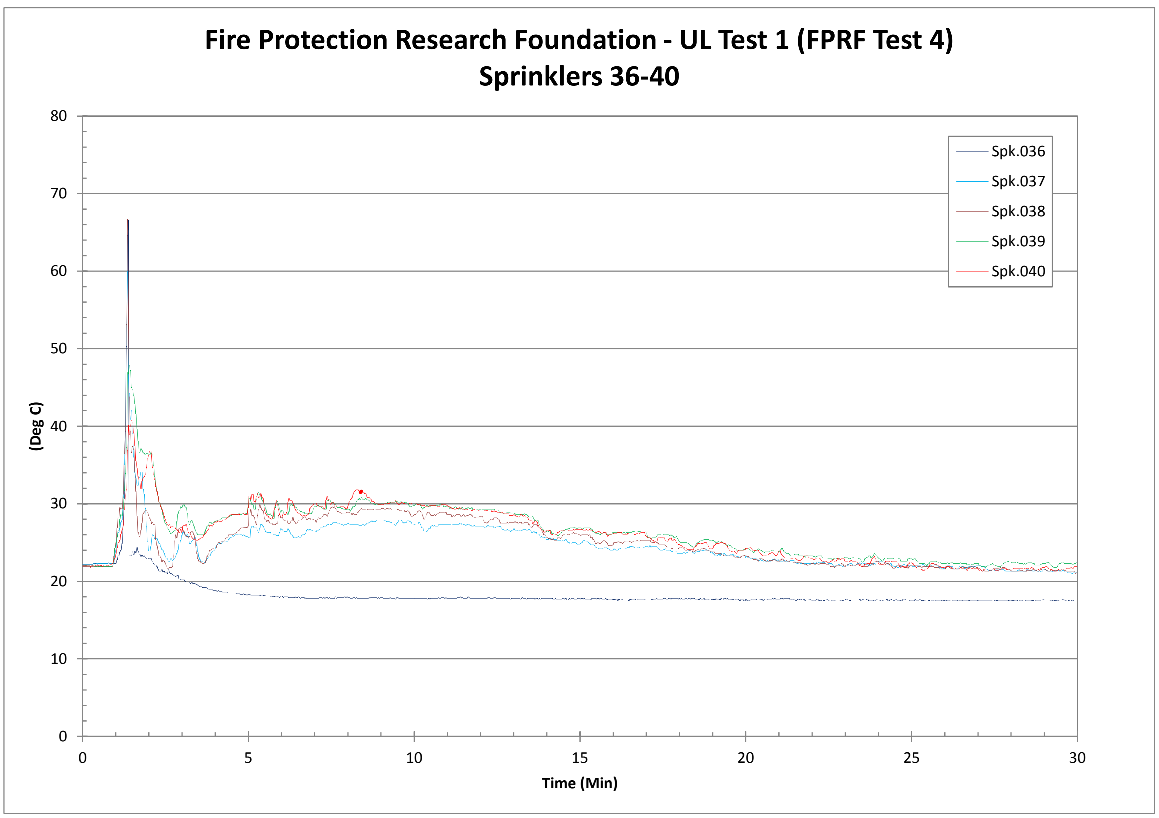

Fire Protection Research Foundation - UL Test 1 (FPRF Test 4)
Sprinklers 11-15
(Deg C)
Time (Min)
Spk.011
Spk.012
Spk.013
Spk.014
Spk.015
0
5
10
15
20
25
30
35
40
45
50

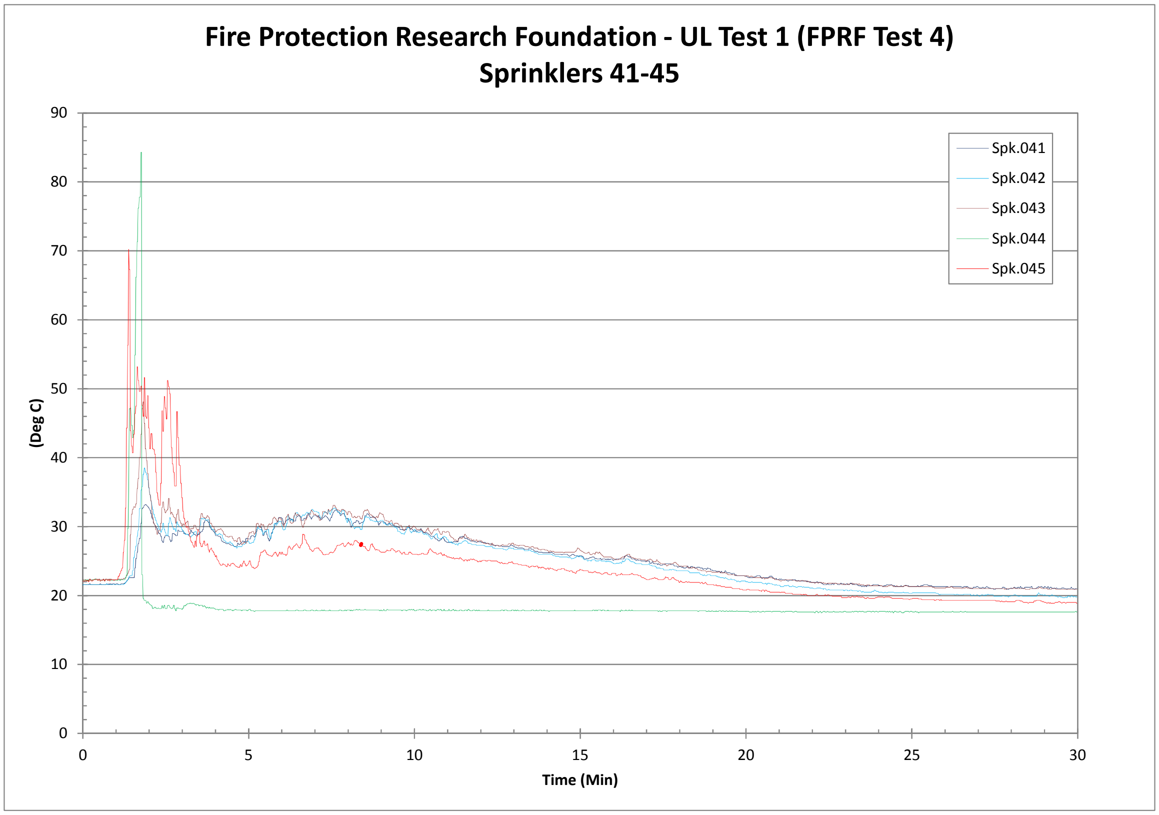

Fire Protection Research Foundation - UL Test 1 (FPRF Test 4)
Sprinklers 16-20
(Deg C)
Time (Min)
Spk.016
Spk.017
Spk.018
Spk.019
Spk.020
0
10
20
30
40
50
60

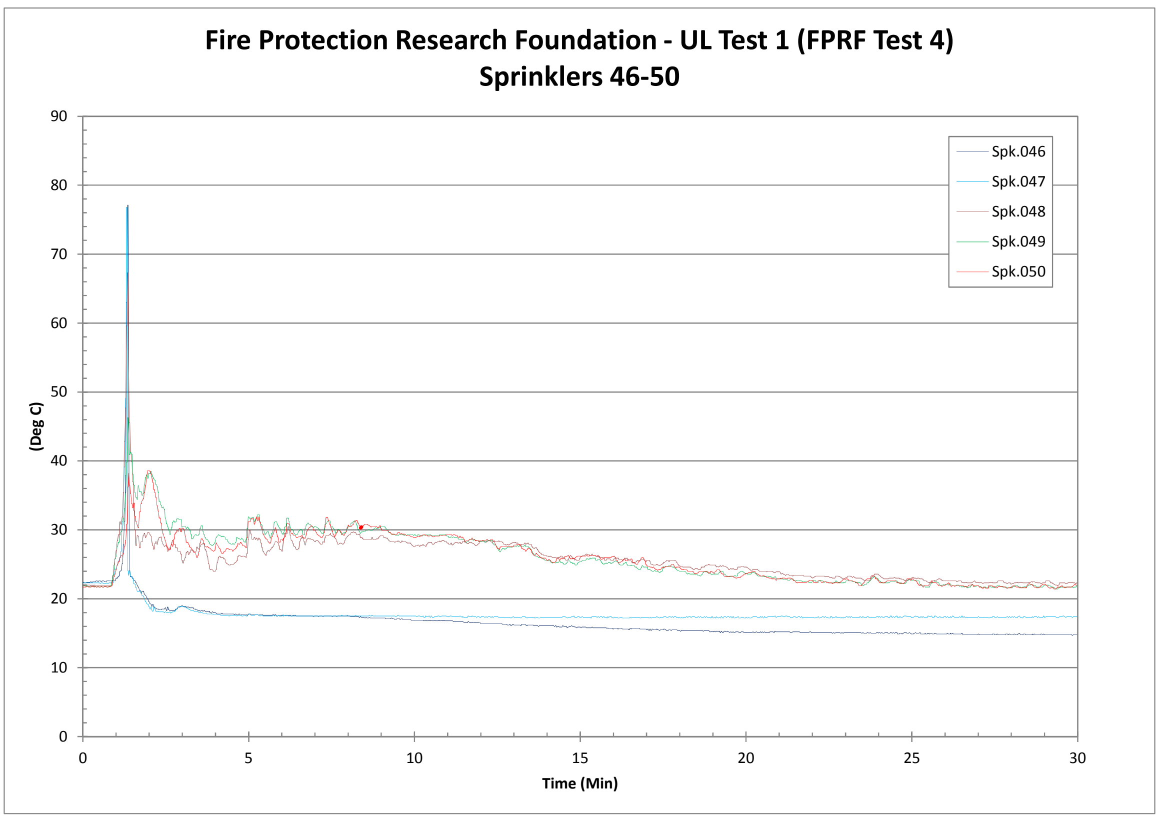

Fire Protection Research Foundation - UL Test 1 (FPRF Test 4)
Sprinklers 21-25
(Deg C)
Time (Min)
0
10
20
30
40
50
60
0
5
10
15
20
25
30
Spk.021
Spk.022
Spk.023
Spk.024
Spk.025

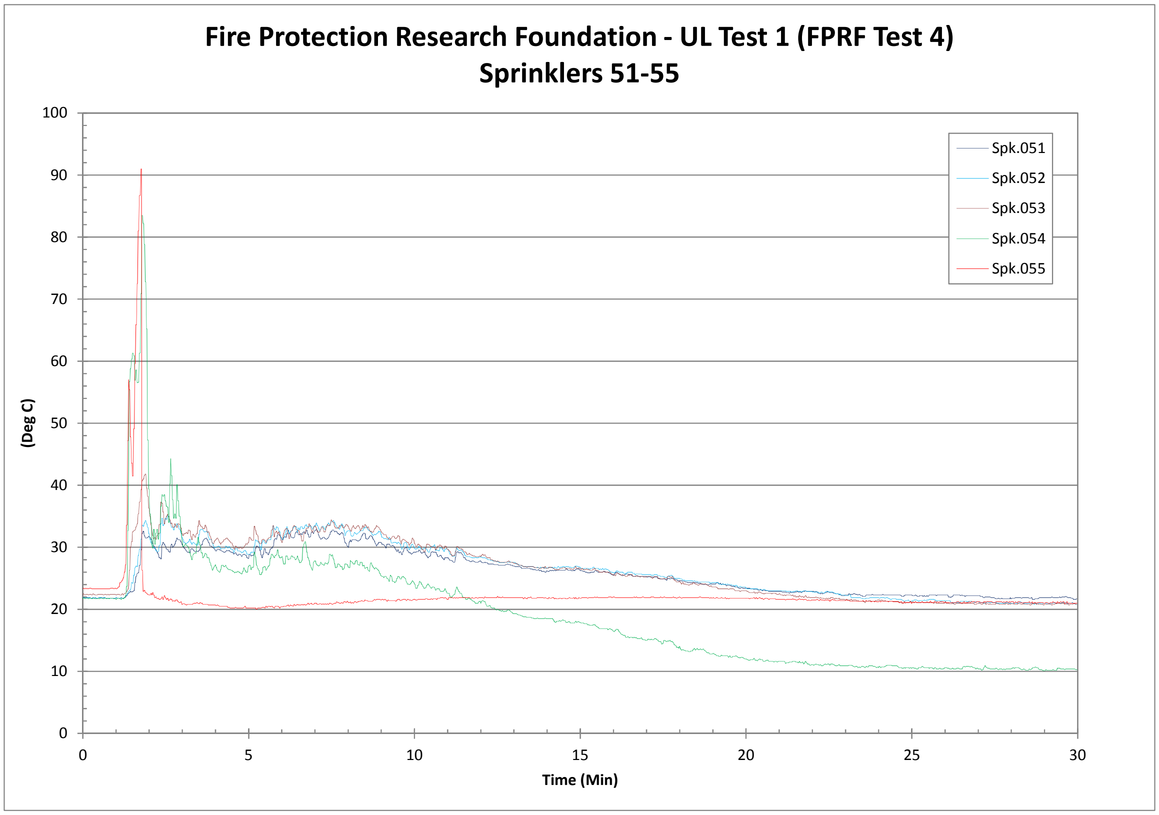

Fire Protection Research Foundation - UL Test 1 (FPRF Test 4)
Sprinklers 26-30
(Deg C)
Time (Min)
0
10
20
30
40
50
60
70
80
0
5
10
15
20
25
30
Spk.026
Spk.027
Spk.028
Spk.029
Spk.030

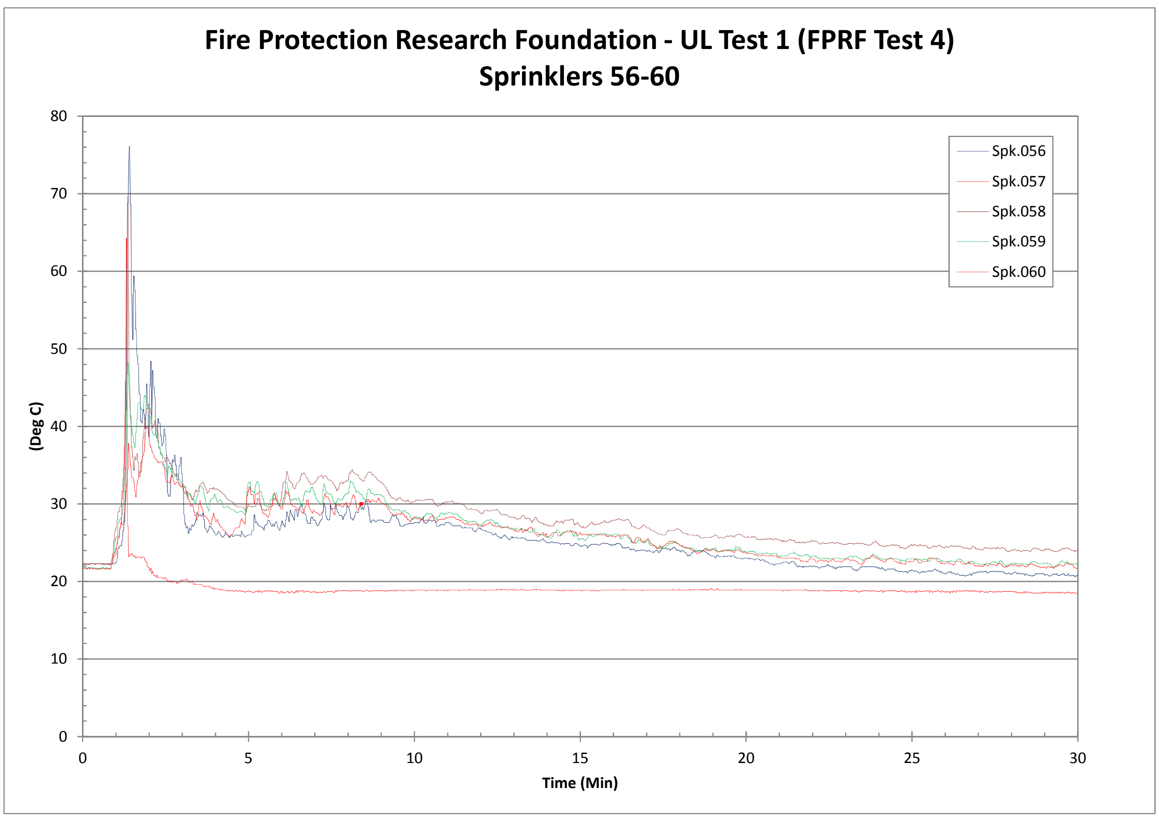

Fire Protection Research Foundation - UL Test 1 (FPRF Test 4)
Sprinklers 31-35
(Deg C)
Time (Min)
Spk.031
Spk.032
Spk.033
Spk.034
Spk.035

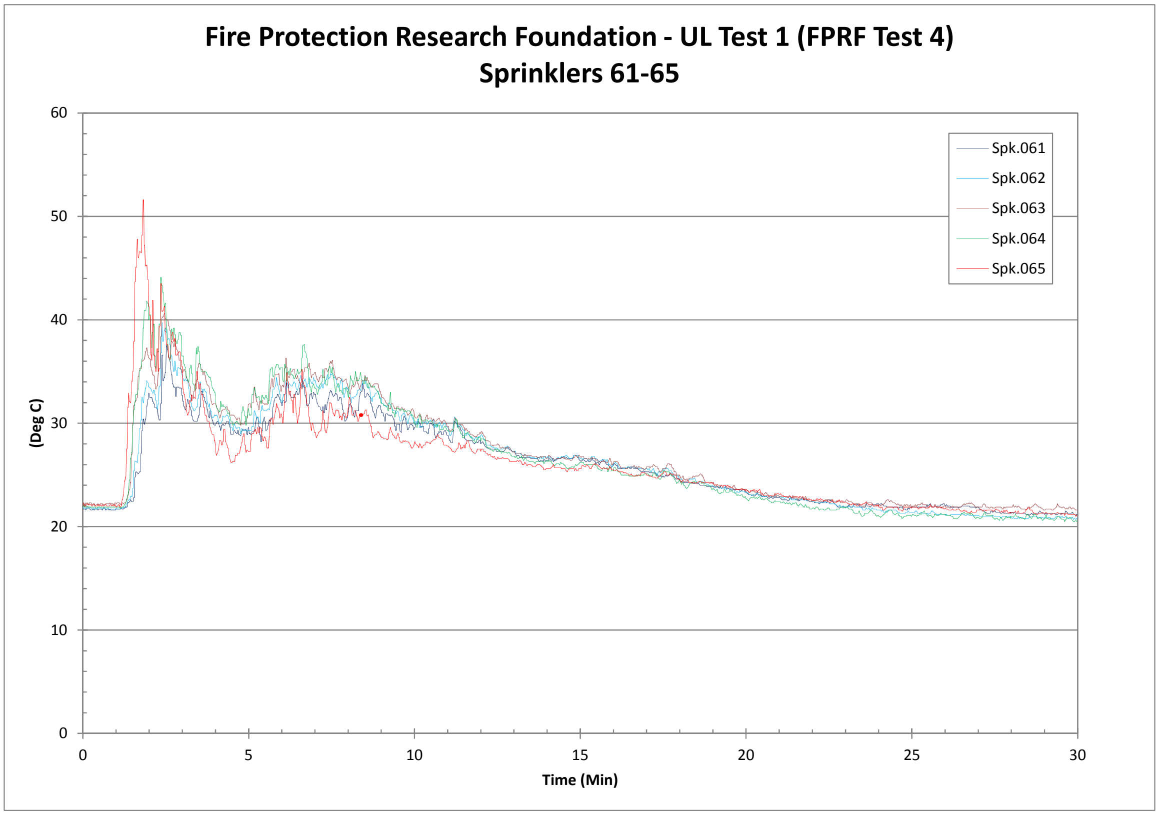

Fire Protection Research Foundation - UL Test 1 (FPRF Test 4)
Sprinklers 36-40
(Deg C)
Time (Min)
Spk.036
Spk.037
Spk.038
Spk.039
Spk.040

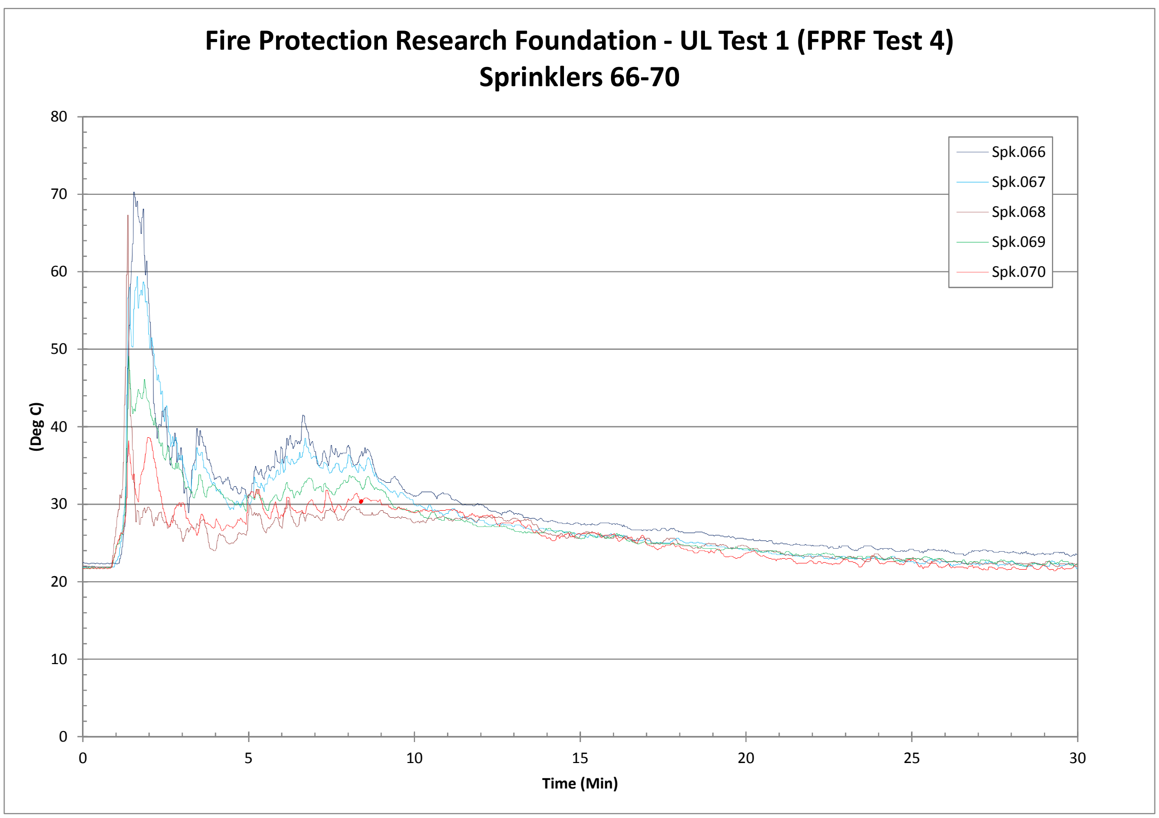

Fire Protection Research Foundation - UL Test 1 (FPRF Test 4)
Sprinklers 41-45
(Deg C)
Time (Min)
Spk.041
Spk.042
Spk.043
Spk.044
Spk.045
0
10
20
30
40
50
60
70
80
90
0
5
10
15
20
25
30

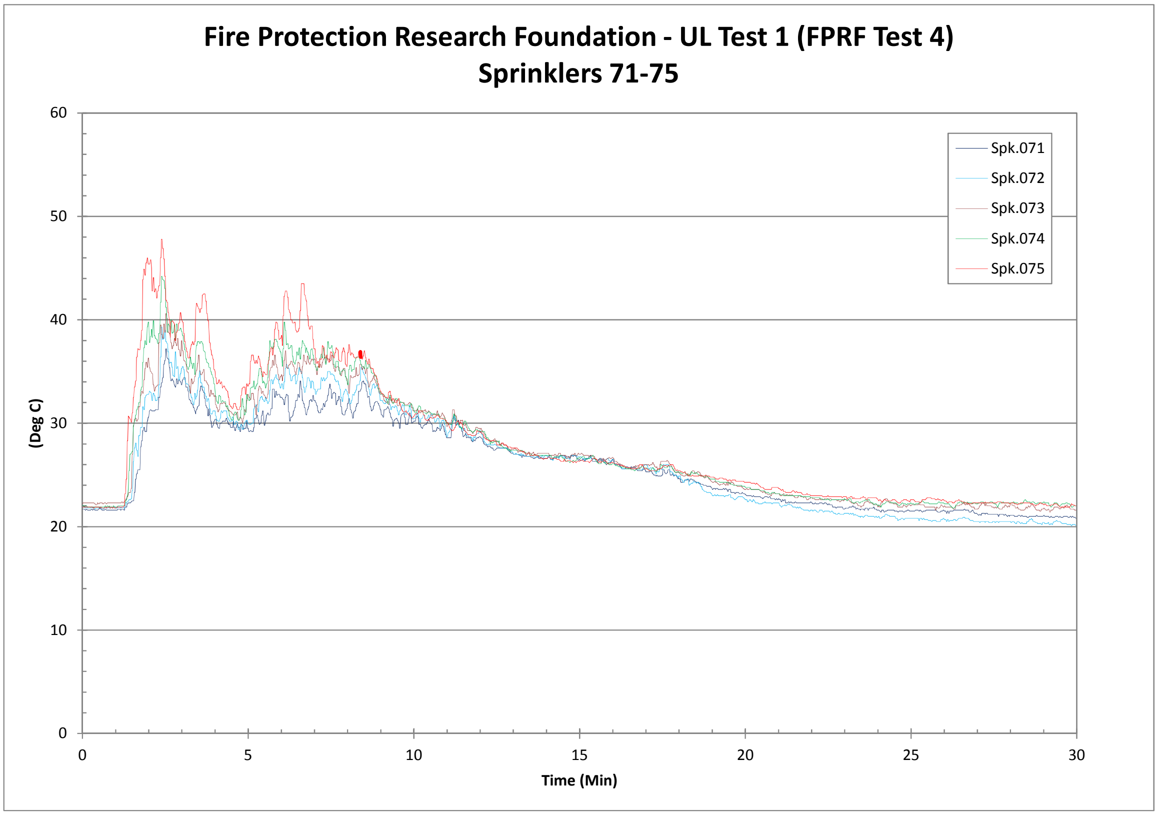

Fire Protection Research Foundation - UL Test 1 (FPRF Test 4)
Sprinklers 46-50
(Deg C)
Time (Min)
Spk.046
Spk.047
Spk.048
Spk.049
Spk.050
0
10
20
30
40
50
60
70
80
90
0
5
10
15
20
25
30

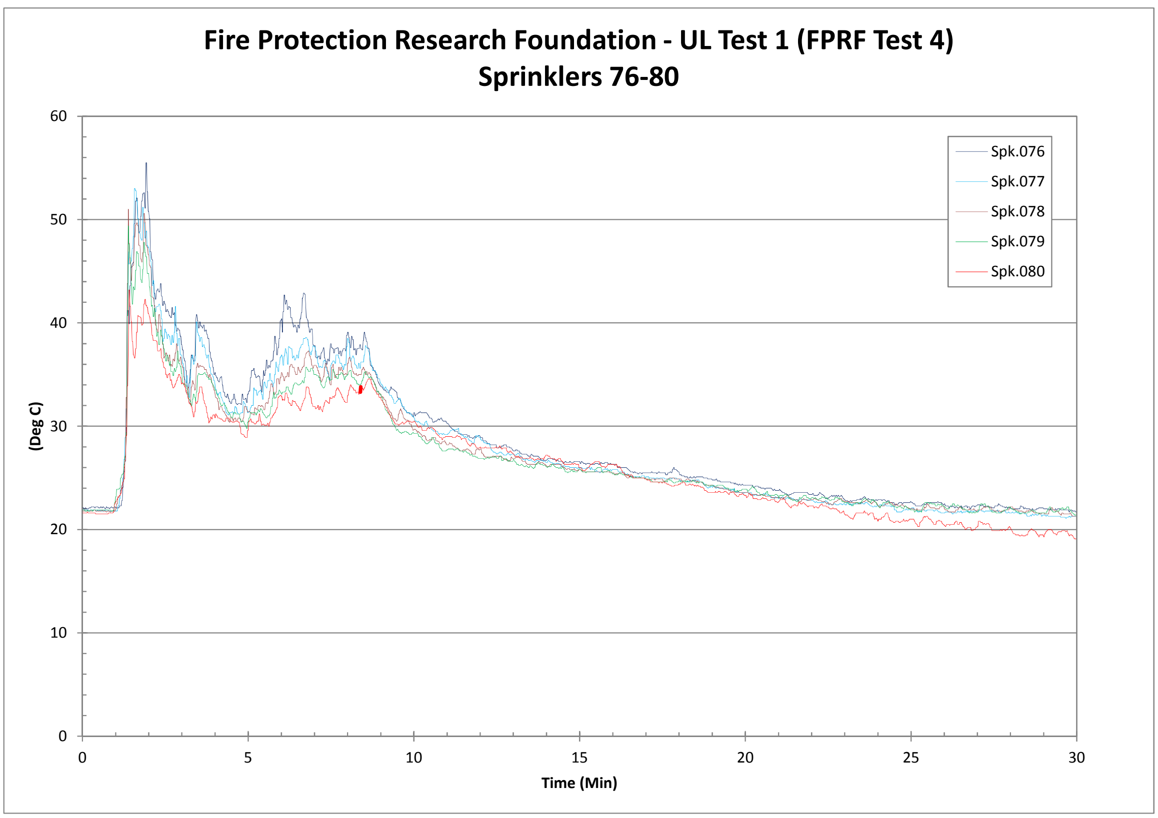

Fire Protection Research Foundation - UL Test 1 (FPRF Test 4)
Sprinklers 51-55
(Deg C)
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
Time (Min)
Spk.051
Spk.052
Spk.053
Spk.054
Spk.055

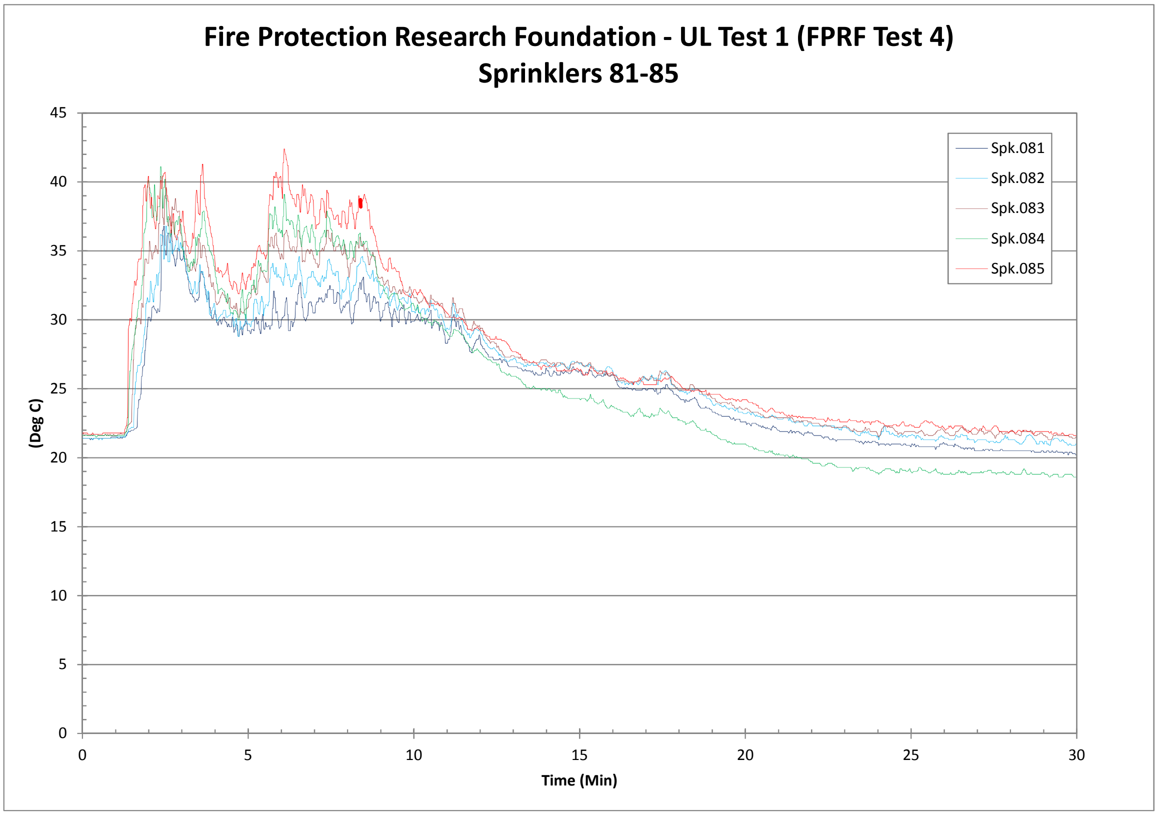

Fire Protection Research Foundation - UL Test 1 (FPRF Test 4)
Sprinklers 56-60
(Deg C)
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
Time (Min)
Spk.056
Spk.057
Spk.058
Spk.059
Spk.060

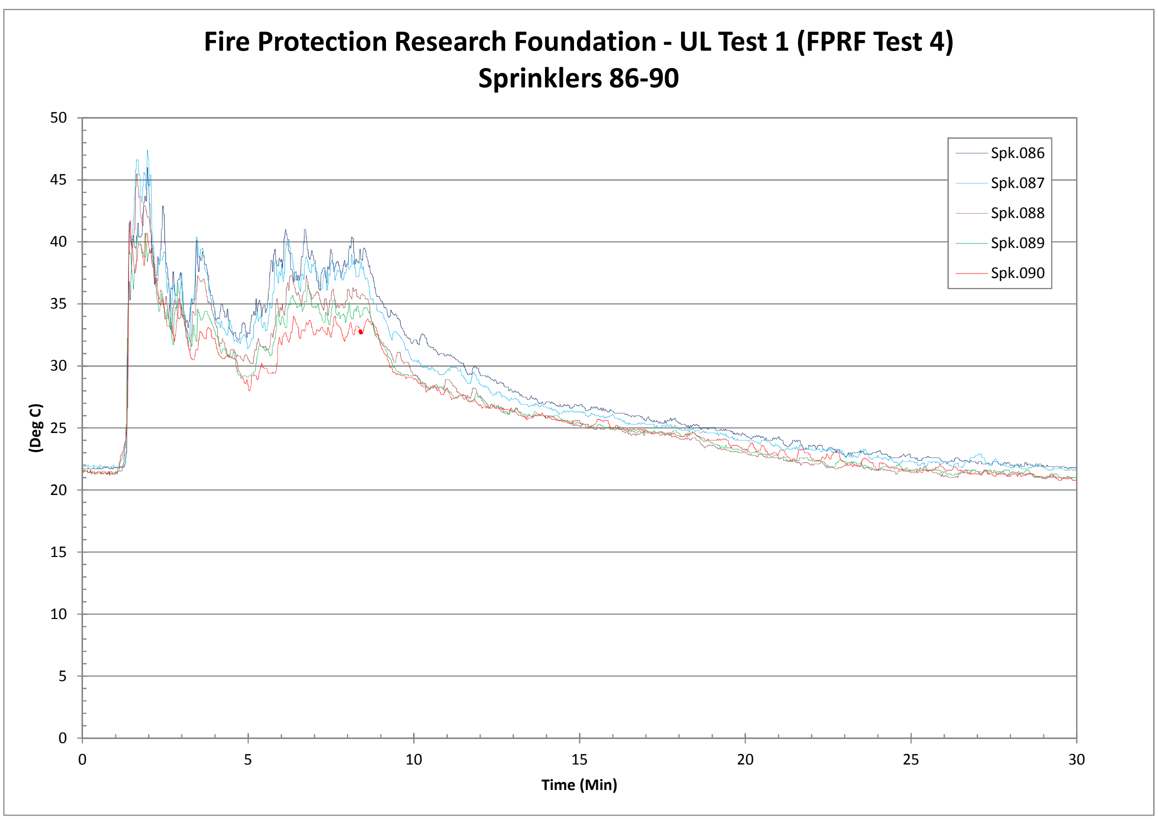

Fire Protection Research Foundation - UL Test 1 (FPRF Test 4)
Sprinklers 61-65
(Deg C)
Time (Min)
Spk.061
Spk.062
Spk.063
Spk.064
Spk.065
0
10
20
30
40
50
60
0
5
10
15
20
25
30

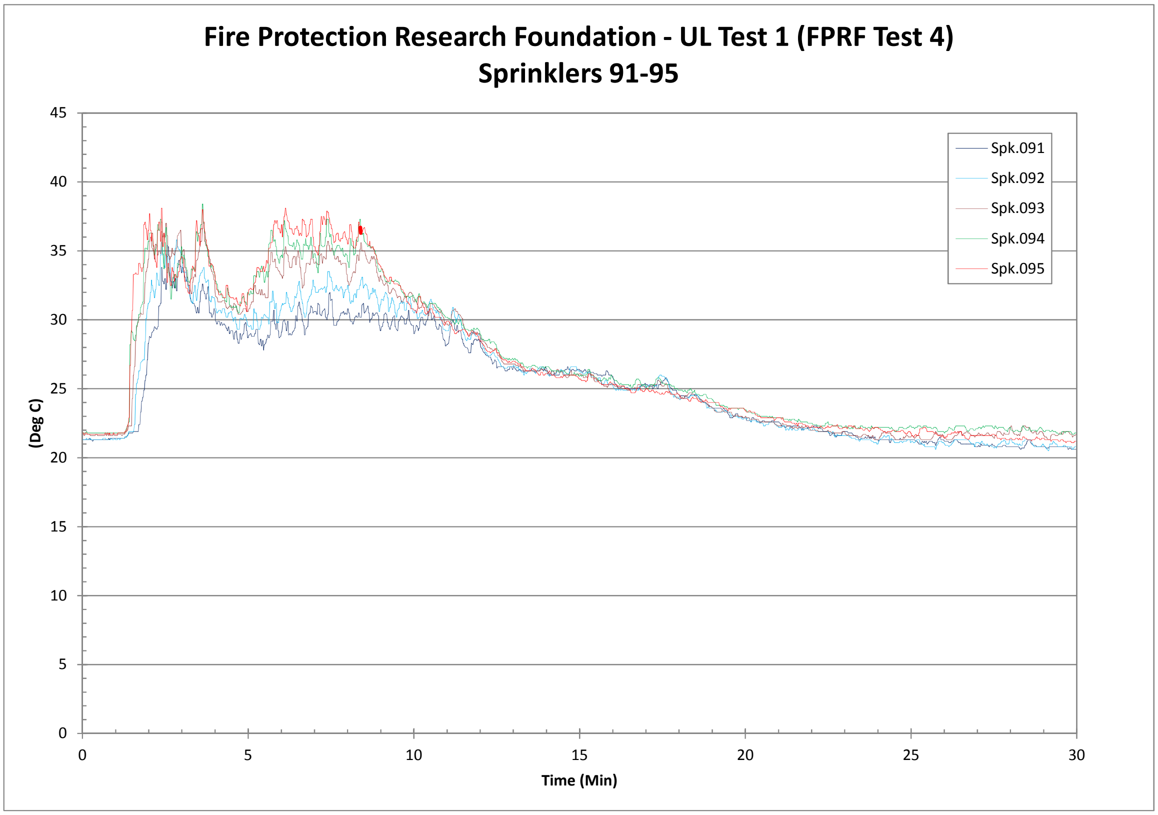

Fire Protection Research Foundation - UL Test 1 (FPRF Test 4)
Sprinklers 66-70
(Deg C)
Time (Min)
Spk.066
Spk.067
Spk.068
Spk.069
Spk.070
0
10
20
30
40
50
60
70
80
0
5
10
15
20
25
30

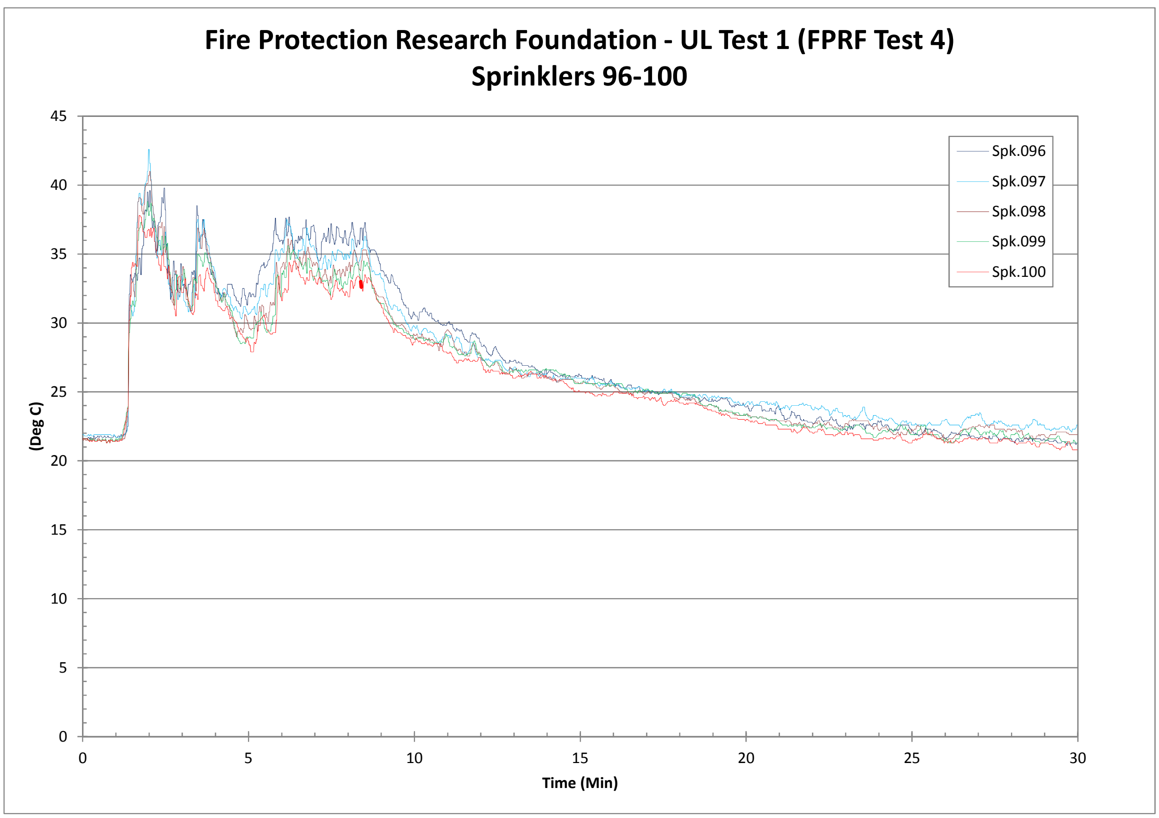

Fire Protection Research Foundation - UL Test 1 (FPRF Test 4)
Sprinklers 71-75
(Deg C)
Time (Min)
Spk.071
Spk.072
Spk.073
Spk.074
Spk.075
0
10
20
30
40
50
60
0
5
10
15
20
25
30

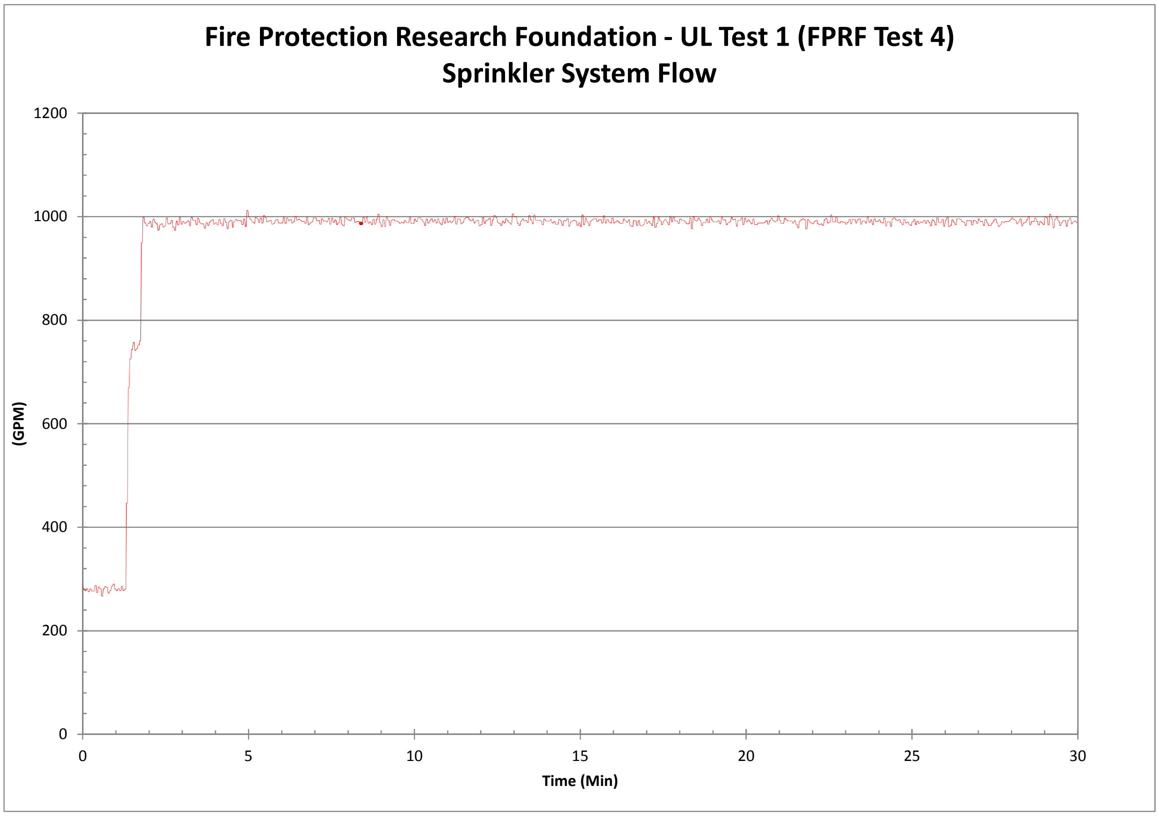

Fire Protection Research Foundation - UL Test 1 (FPRF Test 4)
Sprinklers 76-80
(Deg C)
Time (Min)
Spk.076
Spk.077
Spk.078
Spk.079
Spk.080
0
10
20
30
40
50
60
0
5
10
15
20
25
30

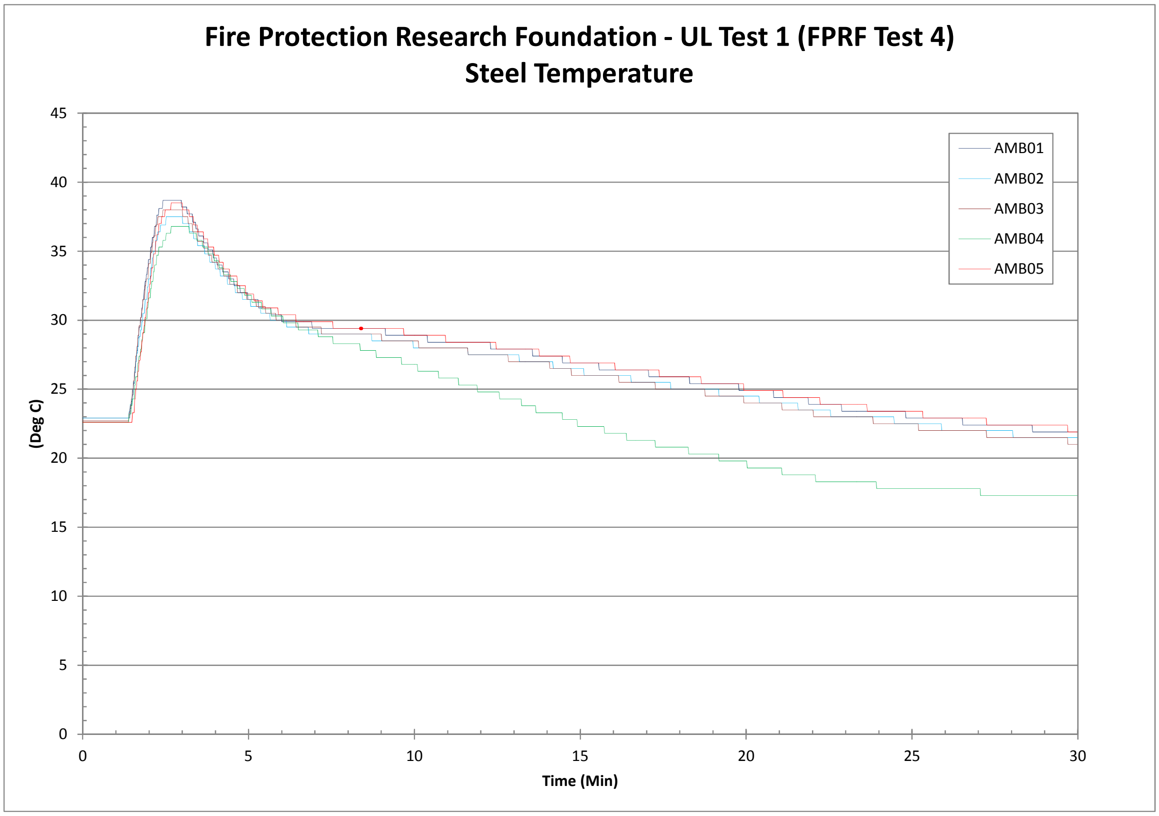

Fire Protection Research Foundation - UL Test 1 (FPRF Test 4)
Sprinklers 81-85
(Deg C)
Time (Min)
Spk.081
Spk.082
Spk.083
Spk.084
Spk.085
0
5
10
15
20
25
30
35
40
45

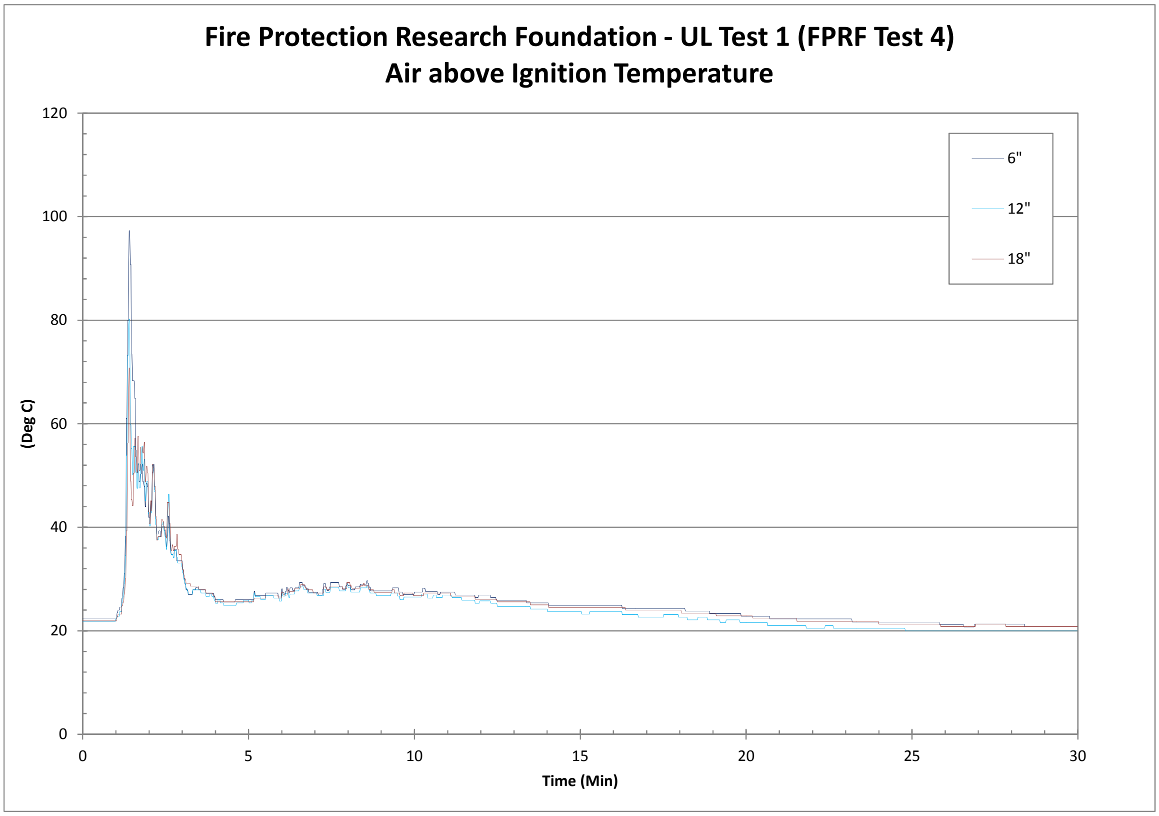

Fire Protection Research Foundation - UL Test 1 (FPRF Test 4)
Sprinklers 86-90
(Deg C)
Time (Min)
Spk.086
Spk.087
Spk.088
Spk.089
Spk.090
0
5
10
15
20
25
30
35
40
45
50

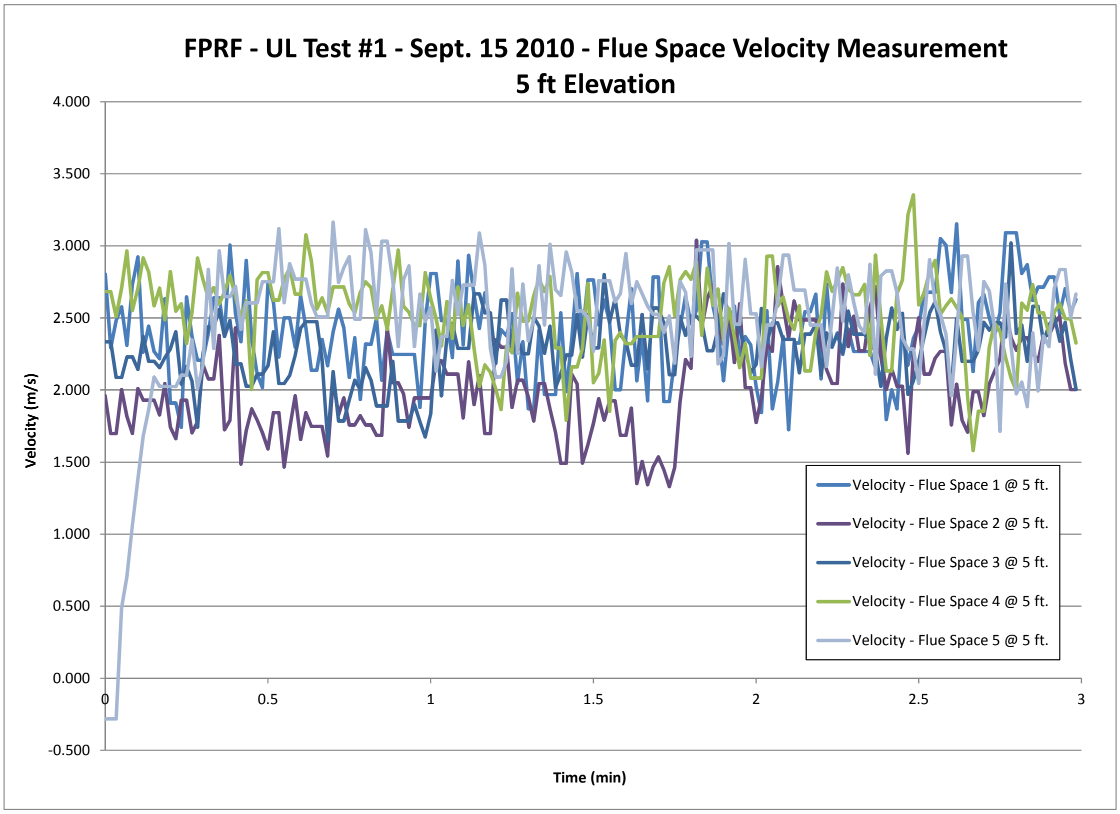

Fire Protection Research Foundation - UL Test 1 (FPRF Test 4)
Sprinklers 91-95
(Deg C)
Time (Min)
Spk.091
Spk.092
Spk.093
Spk.094
Spk.095
0
5
10
15
20
25
30
35
40
45
0
5
10
15
20
25
30

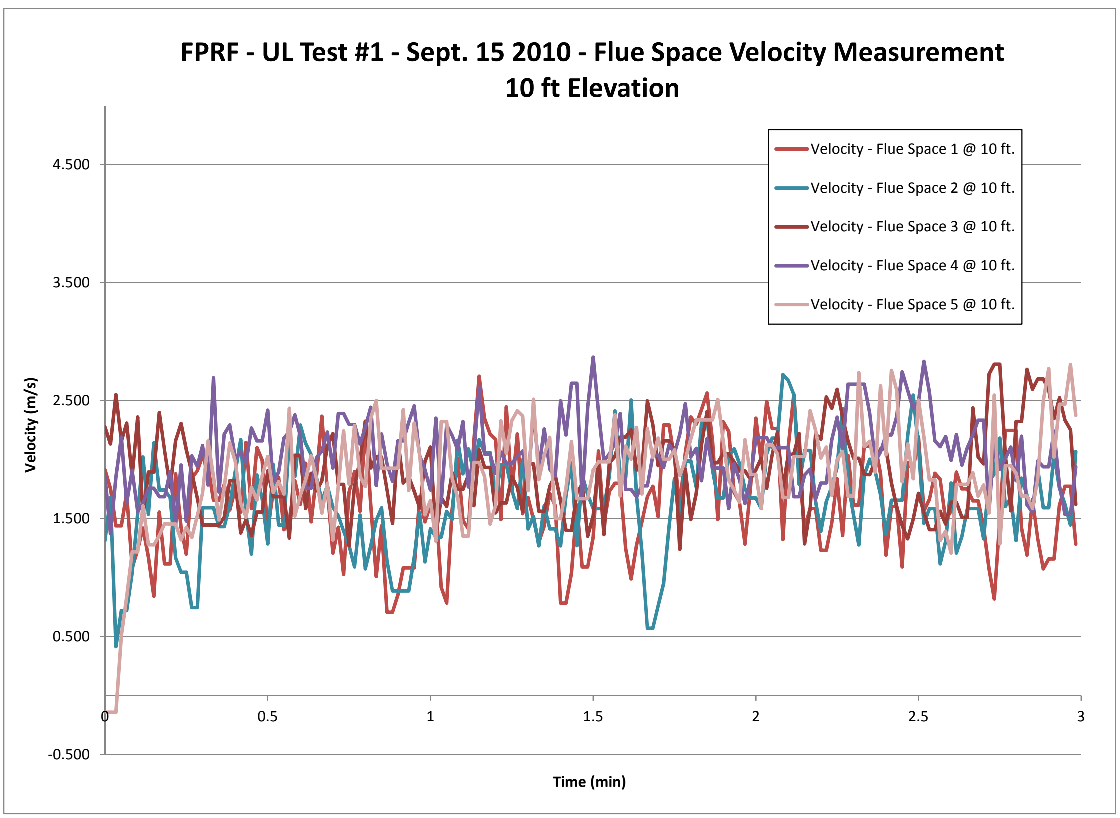

Fire Protection Research Foundation - UL Test 1 (FPRF Test 4)
Sprinklers 96-100
(Deg C)
Time (Min)
Spk.096
Spk.097
Spk.098
Spk.099
Spk.100
0
5
10
15
20
25
30
35
40
45
0
5
10
15
20
25
30

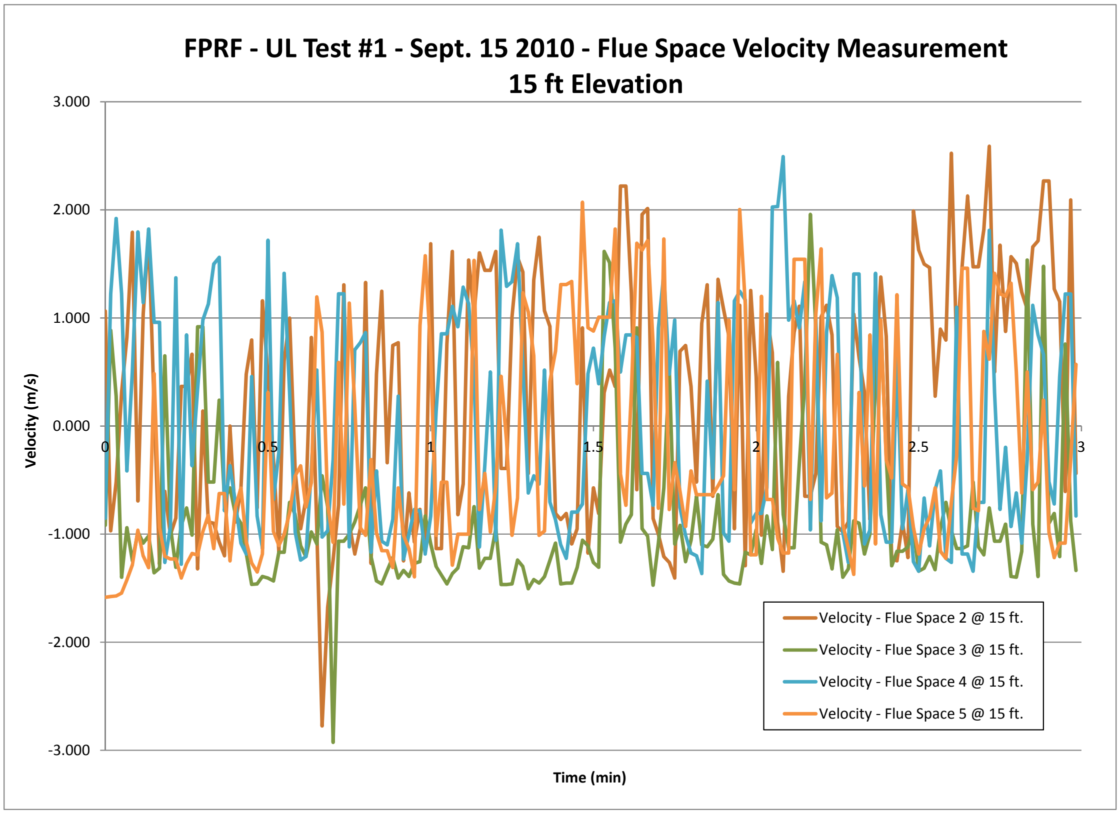

Fire Protection Research Foundation - UL Test 1 (FPRF Test 4)
Sprinkler System Flow
(GPM)
1200
1000
800
600
400
200
0
0
5
10
15
20
25
30
Time (Min)

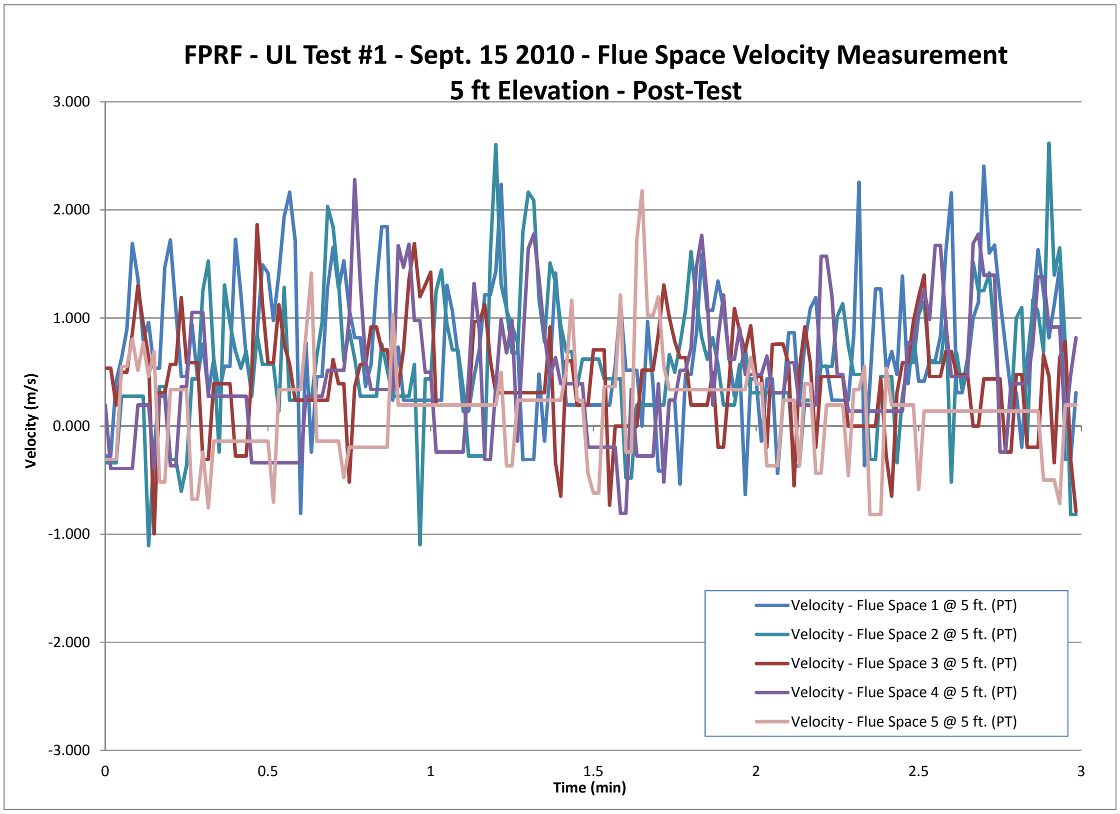

Fire Protection Research Foundation - UL Test 1 (FPRF Test 4)
Steel Temperature
(Deg C)
45
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
Time (Min)
AMB01
AMB02
AMB03
AMB04
AMB05

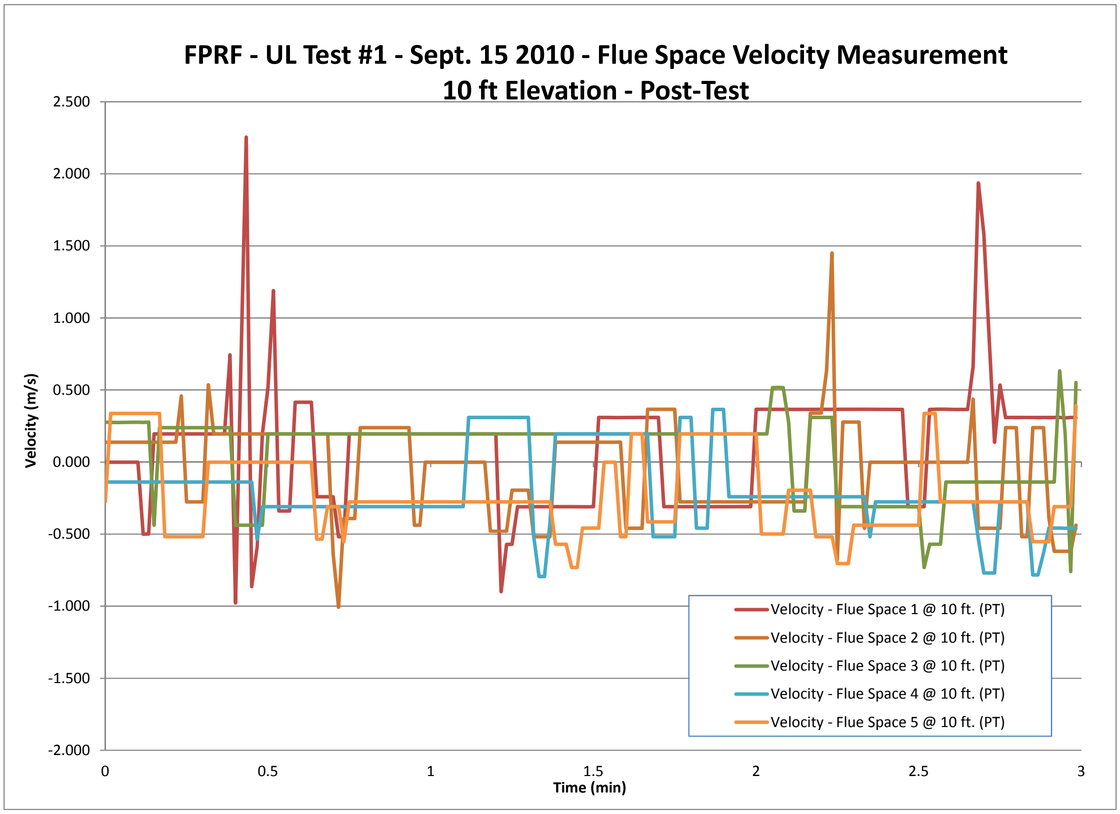

Fire Protection Research Foundation - UL Test 1 (FPRF Test 4)
Air above Ignition Temperature
(Deg C)
Time (Min)
6"
12"
18"
0
20
40
60
80
100
120
0
5
10
15
20
25
30

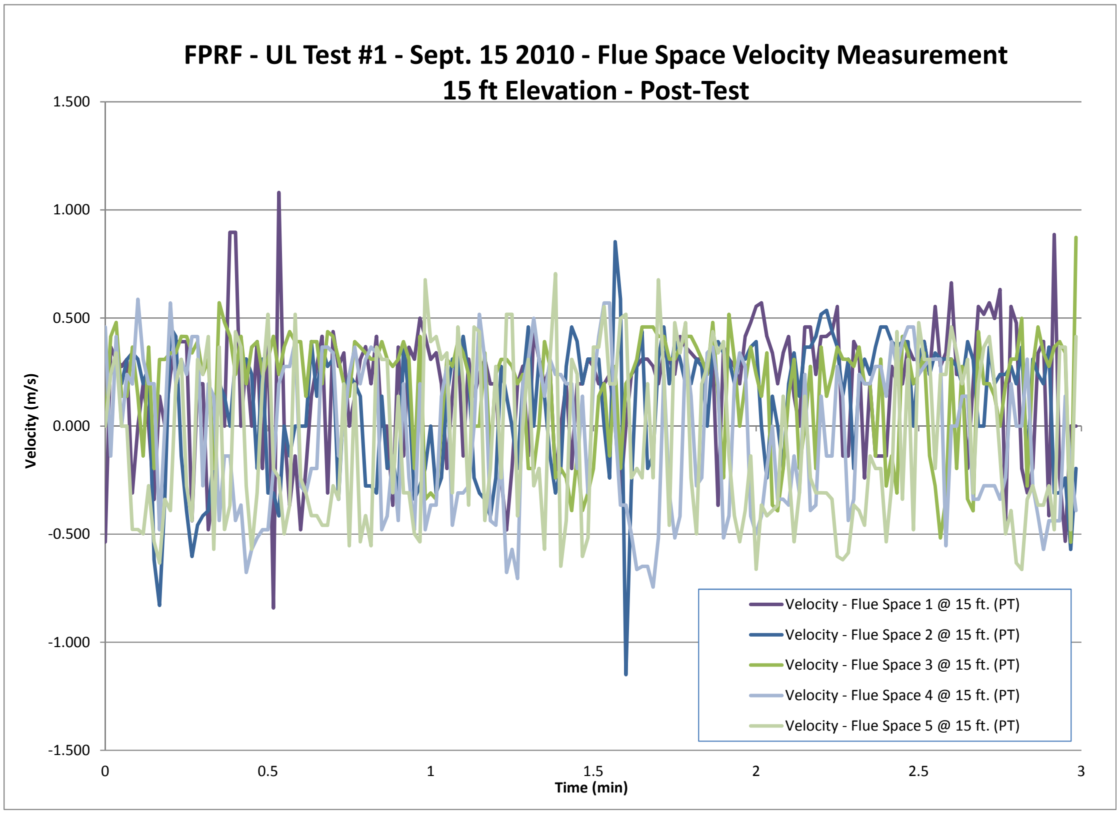

FPRF - UL Test #1 - Sept. 15 2010 - Flue Space Velocity Measurement
5 ft Elevation
4.000
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
-0.500
Velocity (m/s)
0
0.5
1
1.5
2
2.5
3
Time (min)
Velocity - Flue Space 1 @ 5 ft.
Velocity - Flue Space 2 @ 5 ft.
Velocity - Flue Space 3 @ 5 ft.
Velocity - Flue Space 4 @ 5 ft.
Velocity - Flue Space 5 @ 5 ft.


FPRF - UL Test #1 - Sept. 15 2010 - Flue Space Velocity Measurement
10 ft Elevation
4.500
3.500
2.500
1.500
0.500
-0.500
Velocity (m/s)
0
0.5
1
1.5
2
2.5
3
Time (min)
Velocity - Flue Space 1 @ 10 ft.
Velocity - Flue Space 2 @ 10 ft.
Velocity - Flue Space 3 @ 10 ft.
Velocity - Flue Space 4 @ 10 ft.
Velocity - Flue Space 5 @ 10 ft.


FPRF - UL Test #1 - Sept. 15 2010 - Flue Space Velocity Measurement
15 ft Elevation
Velocity (m/s)
3.000
2.000
1.000
0.000
-1.000
-2.000
-3.000
0
0.5
1
1.5
2
2.5
3
Time (min)
Velocity - Flue Space 2 @ 15 ft.
Velocity - Flue Space 3 @ 15 ft.
Velocity - Flue Space 4 @ 15 ft.
Velocity - Flue Space 5 @ 15 ft.


FPRF - UL Test #1 - Sept. 15 2010 - Flue Space Velocity Measurement
5 ft Elevation - Post-Test
Velocity (m/s)
3.000
2.000
1.000
0.000
-1.000
-2.000
-3.000
0
0.5
1
1.5
2
2.5
3
Time (min)
Velocity - Flue Space 1 @ 5 ft. (PT)
Velocity - Flue Space 2 @ 5 ft. (PT)
Velocity - Flue Space 3 @ 5 ft. (PT)
Velocity - Flue Space 4 @ 5 ft. (PT)
Velocity - Flue Space 5 @ 5 ft. (PT)


FPRF - UL Test #1 - Sept. 15 2010 - Flue Space Velocity Measurement
10 ft Elevation - Post-Test
Velocity (m/s)
2.500
2.000
1.500
1.000
0.500
0.000
-0.500
-1.000
-1.500
-2.000
0
0.5
1
1.5
2
2.5
3
Time (min)
Velocity - Flue Space 1 @ 10 ft. (PT)
Velocity - Flue Space 2 @ 10 ft. (PT)
Velocity - Flue Space 3 @ 10 ft. (PT)
Velocity - Flue Space 4 @ 10 ft. (PT)
Velocity - Flue Space 5 @ 10 ft. (PT)

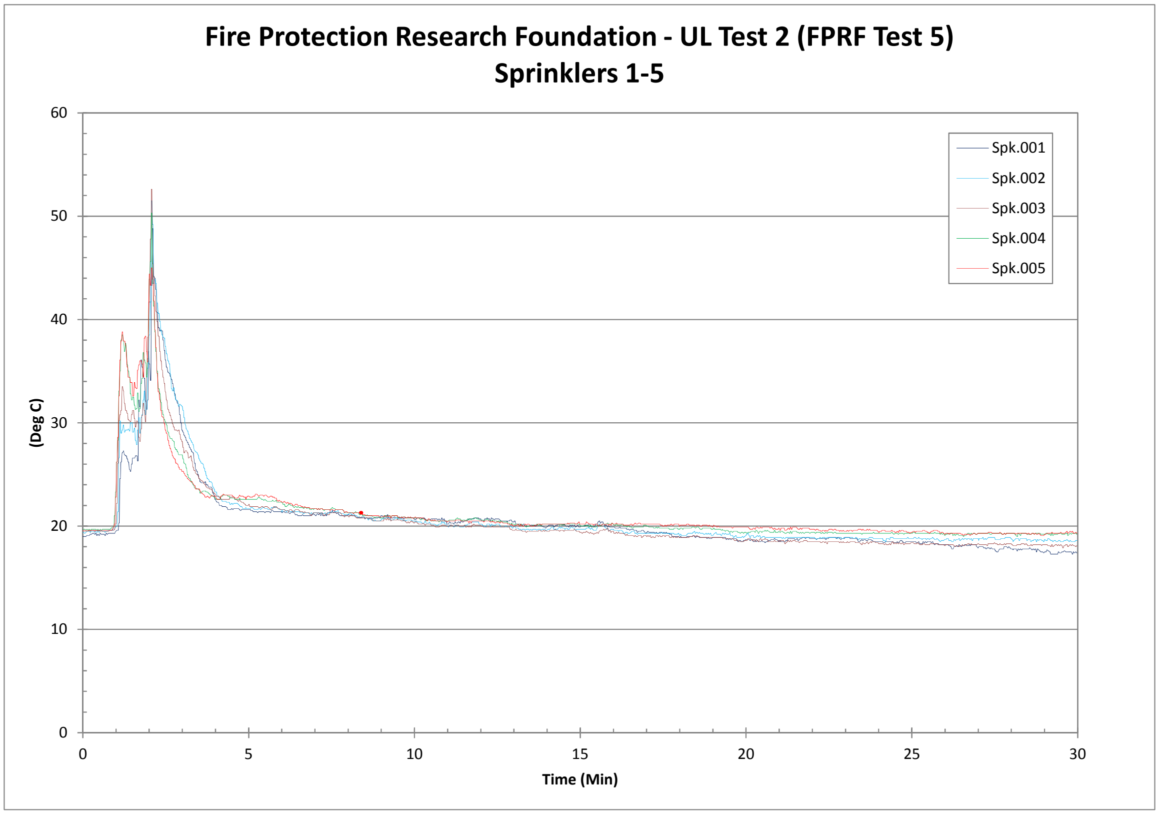

FPRF - UL Test #1 - Sept. 15 2010 - Flue Space Velocity Measurement
15 ft Elevation - Post-Test
Velocity (m/s)
1.500
1.000
0.500
0.000
-0.500
-1.000
-1.500
0
0.5
1
1.5
2
2.5
3
Time (min)
Velocity - Flue Space 1 @ 15 ft. (PT)
Velocity - Flue Space 2 @ 15 ft. (PT)
Velocity - Flue Space 3 @ 15 ft. (PT)
Velocity - Flue Space 4 @ 15 ft. (PT)
Velocity - Flue Space 5 @ 15 ft. (PT)

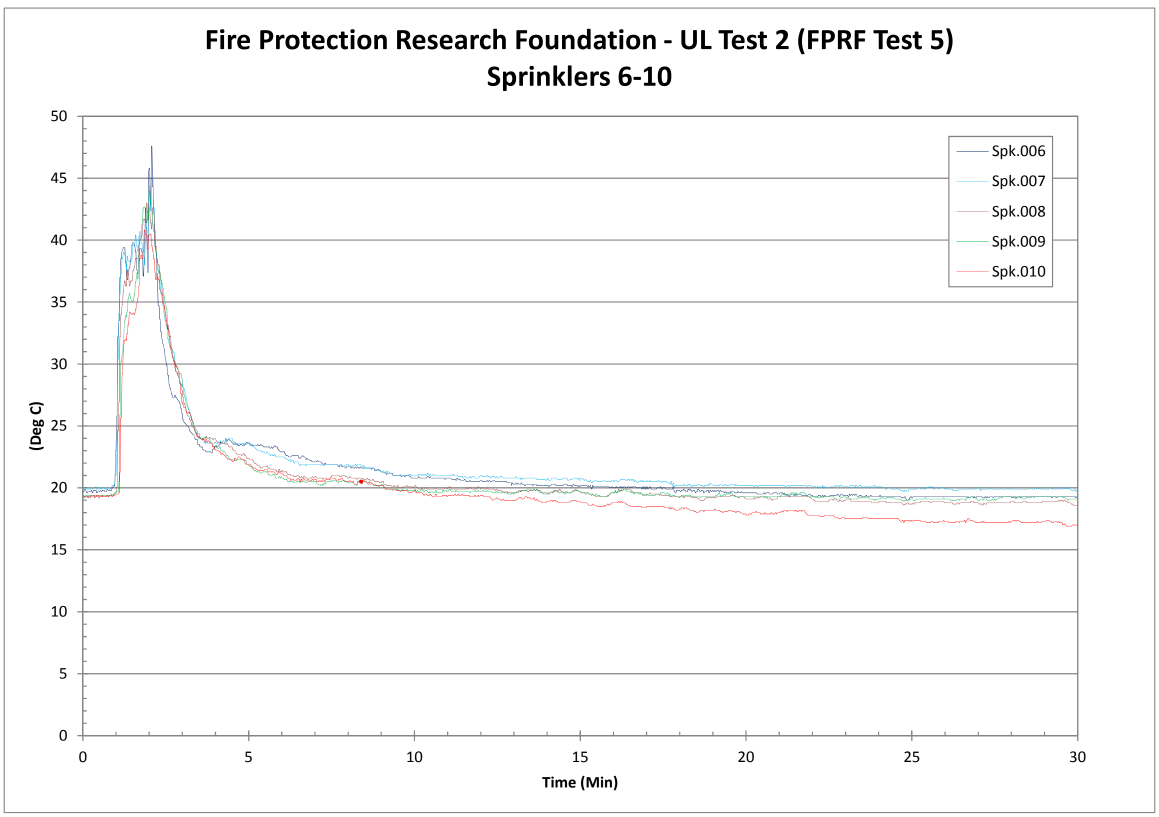
APPENDIX B

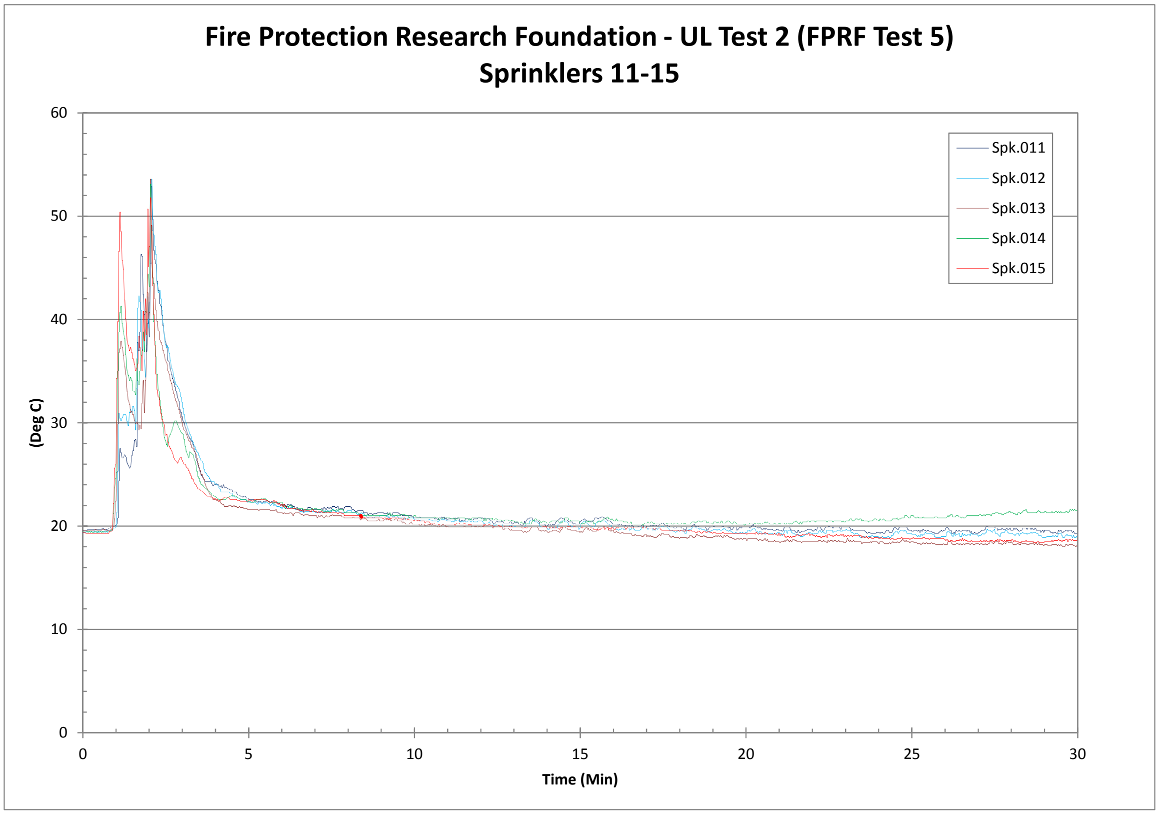
Graphical Presentation of

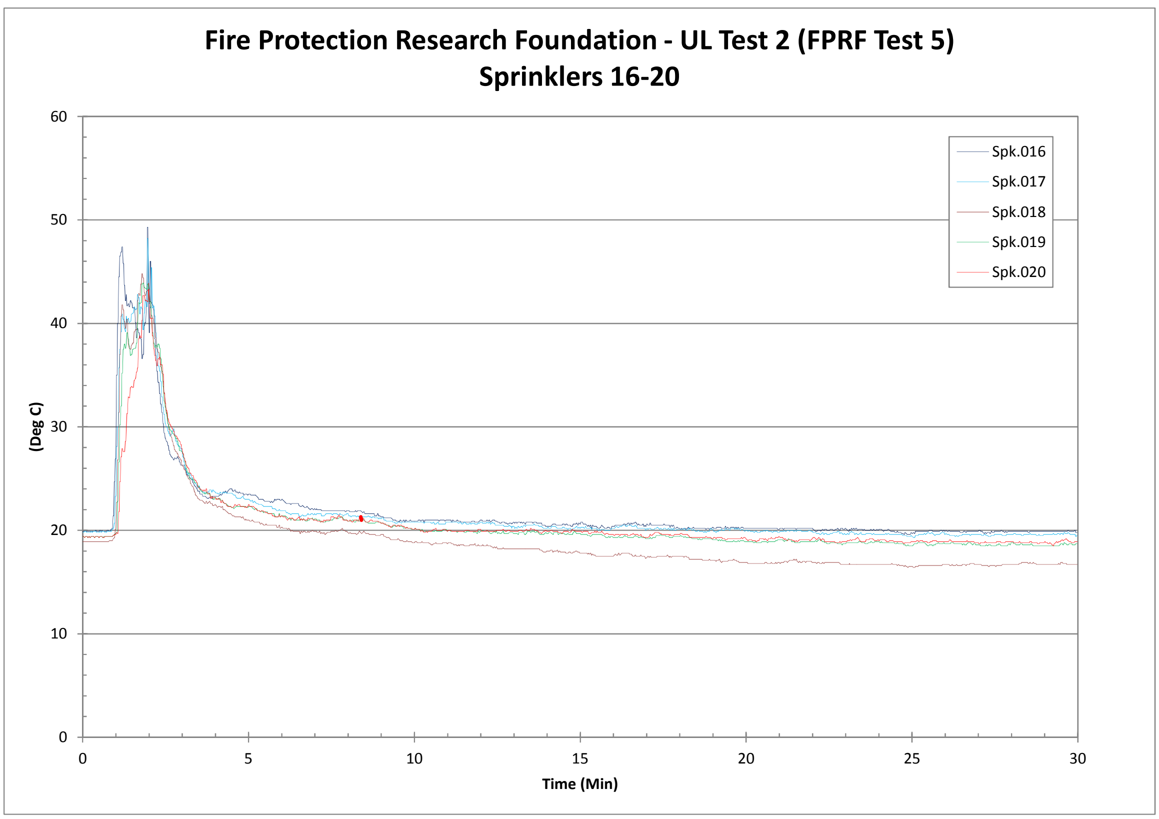
Gas Temperatures, Steel Temperatures, System Waterflow and Velocities - Test 2

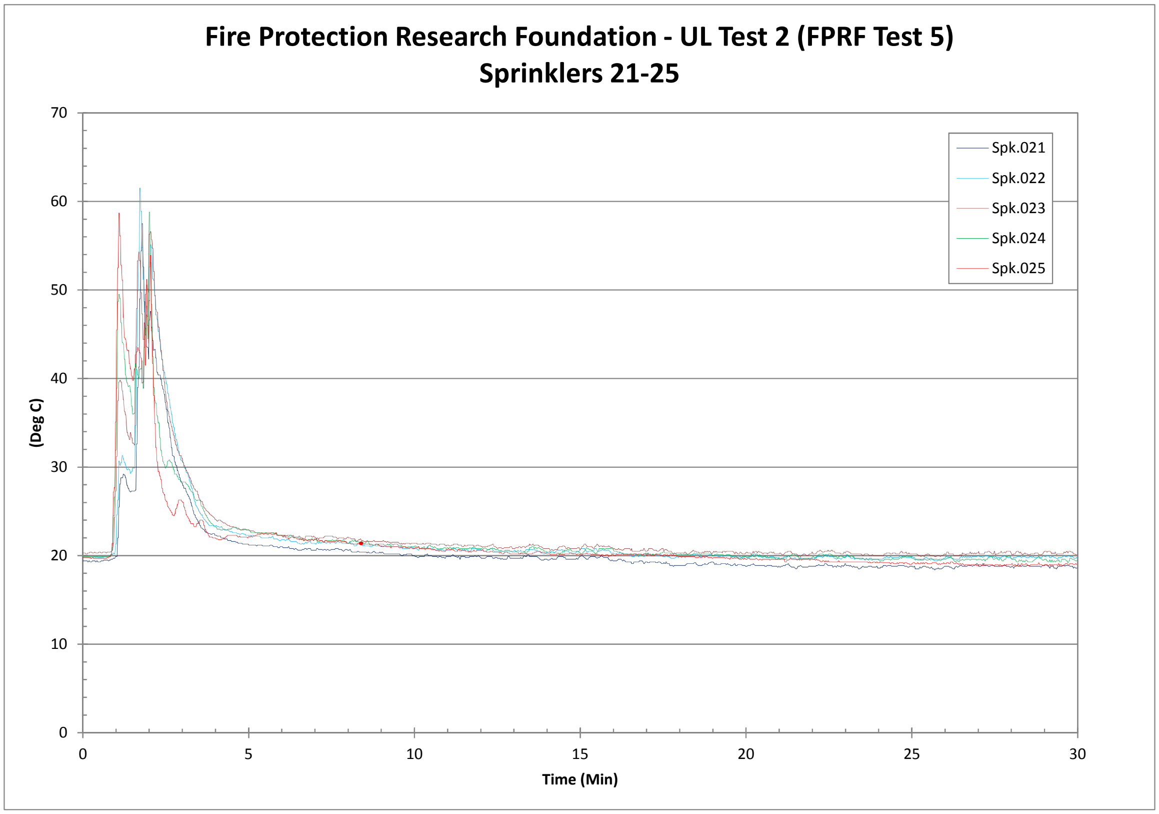
Index: Page

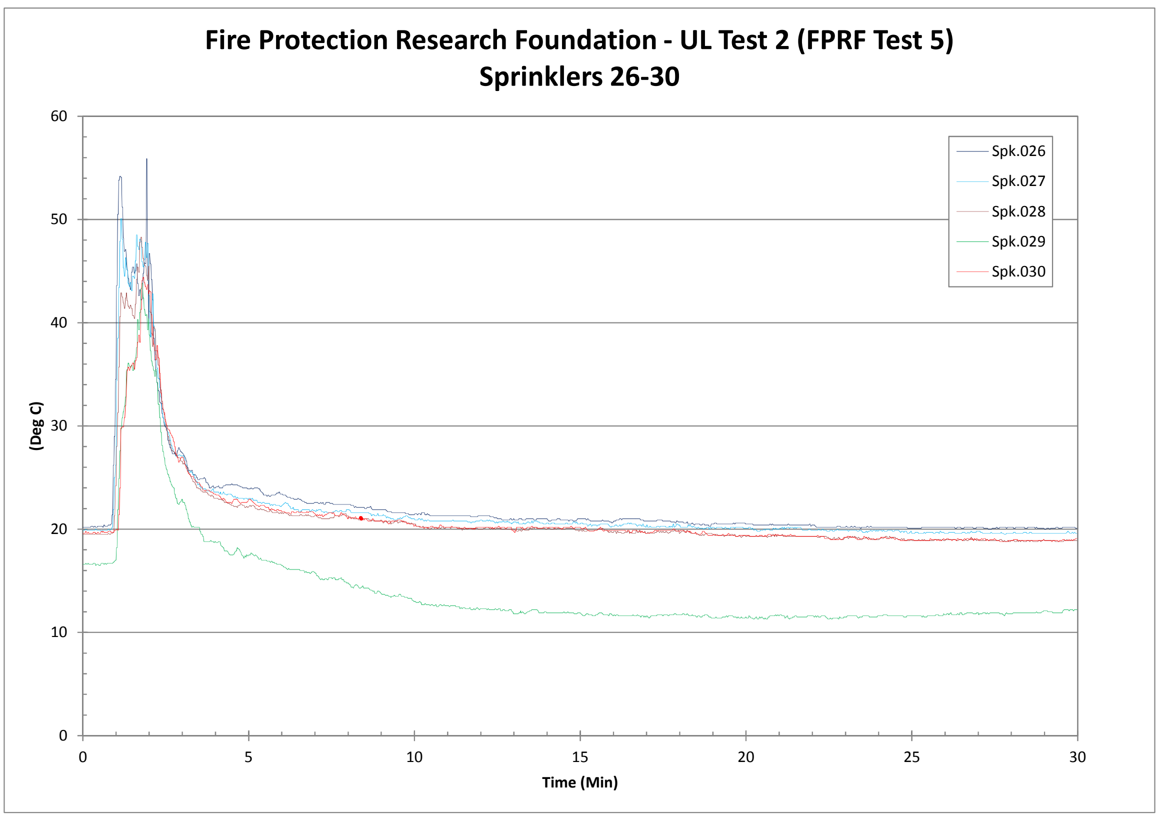

Fire Protection Research Foundation - UL Test 2 (FPRF Test 5)
Sprinklers 1-5
(Deg C)
0
10
20
30
40
50
60
Time (Min)
0
5
10
15
20
25
30
Spk.001
Spk.002
Spk.003
Spk.004
Spk.005

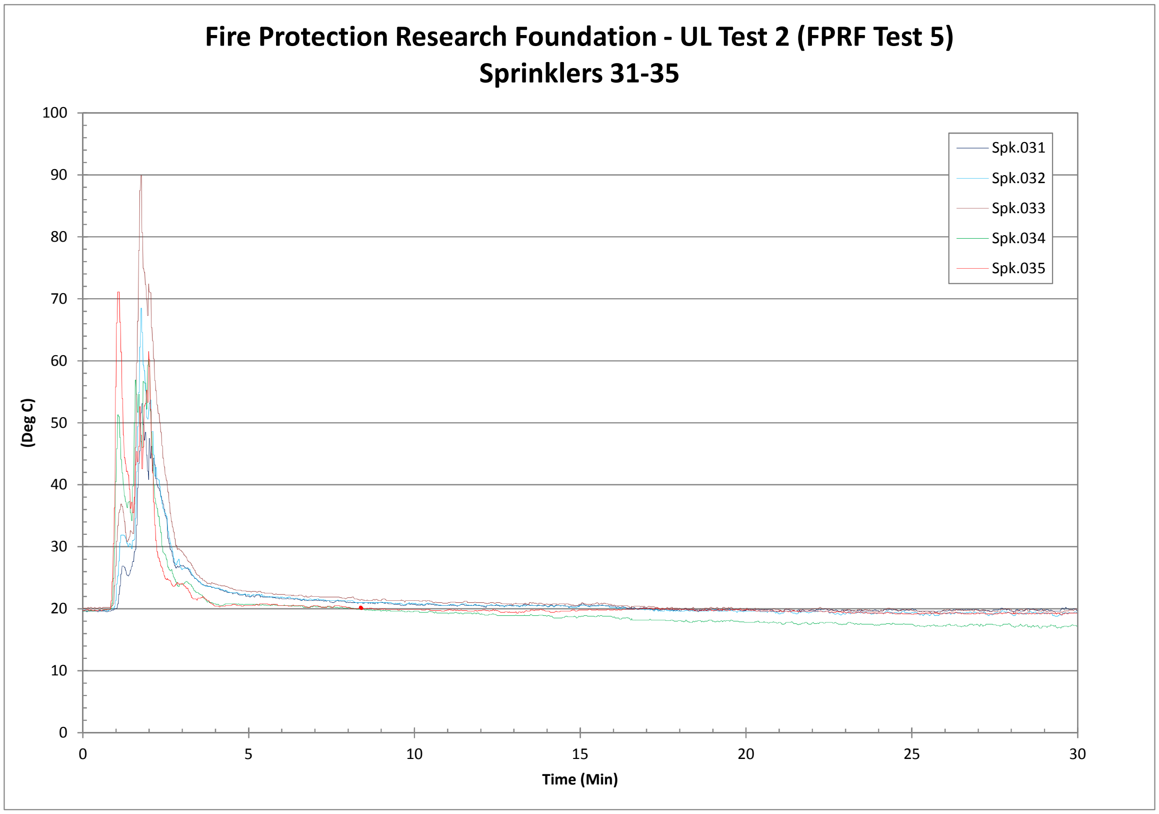

Fire Protection Research Foundation - UL Test 2 (FPRF Test 5)
Sprinklers 6-10
(Deg C)
0
5
10
15
20
25
30
35
40
45
50
Time (Min)
0
5
10
15
20
25
30
Spk.006
Spk.007
Spk.008
Spk.009
Spk.010

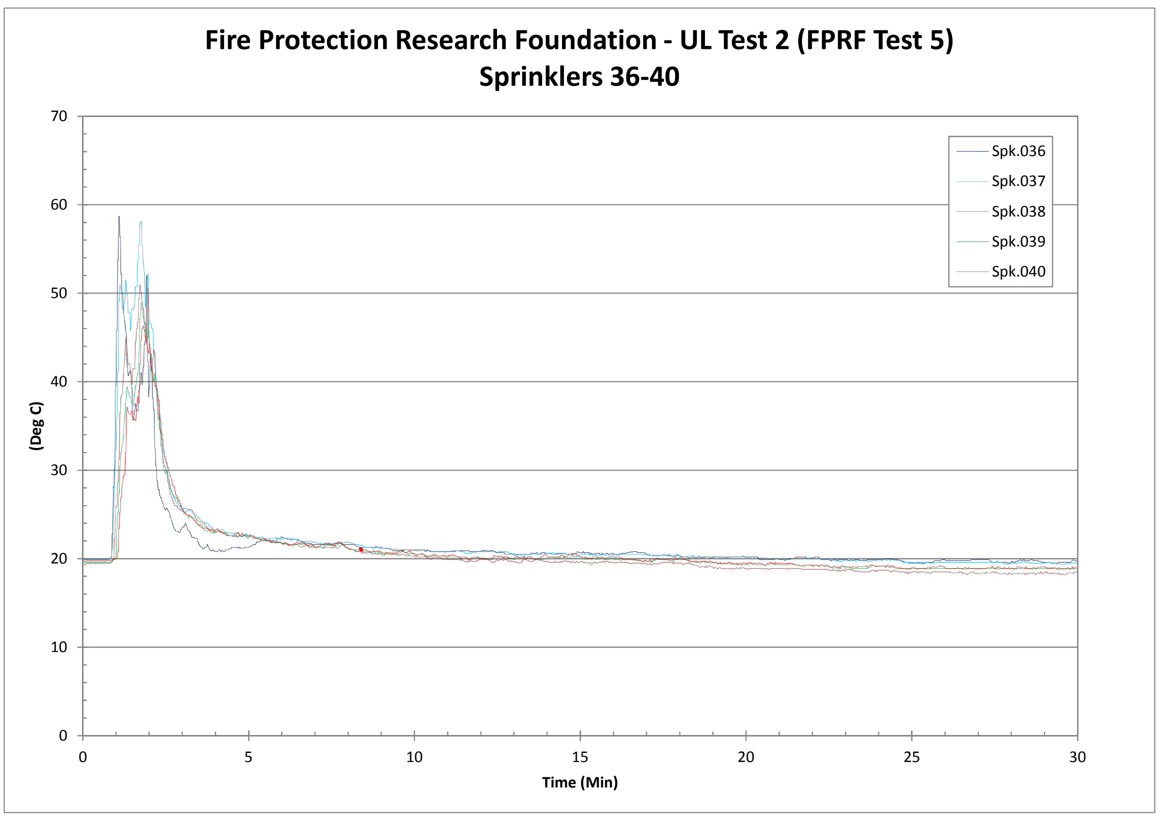

Fire Protection Research Foundation - UL Test 2 (FPRF Test 5)
Sprinklers 11-15
Spk.011
Spk.012
Spk.013
Spk.014
Spk.015
(Deg C)
Time (Min)
0
10
20
30
40
50
60
0
5
10
15
20
25
30

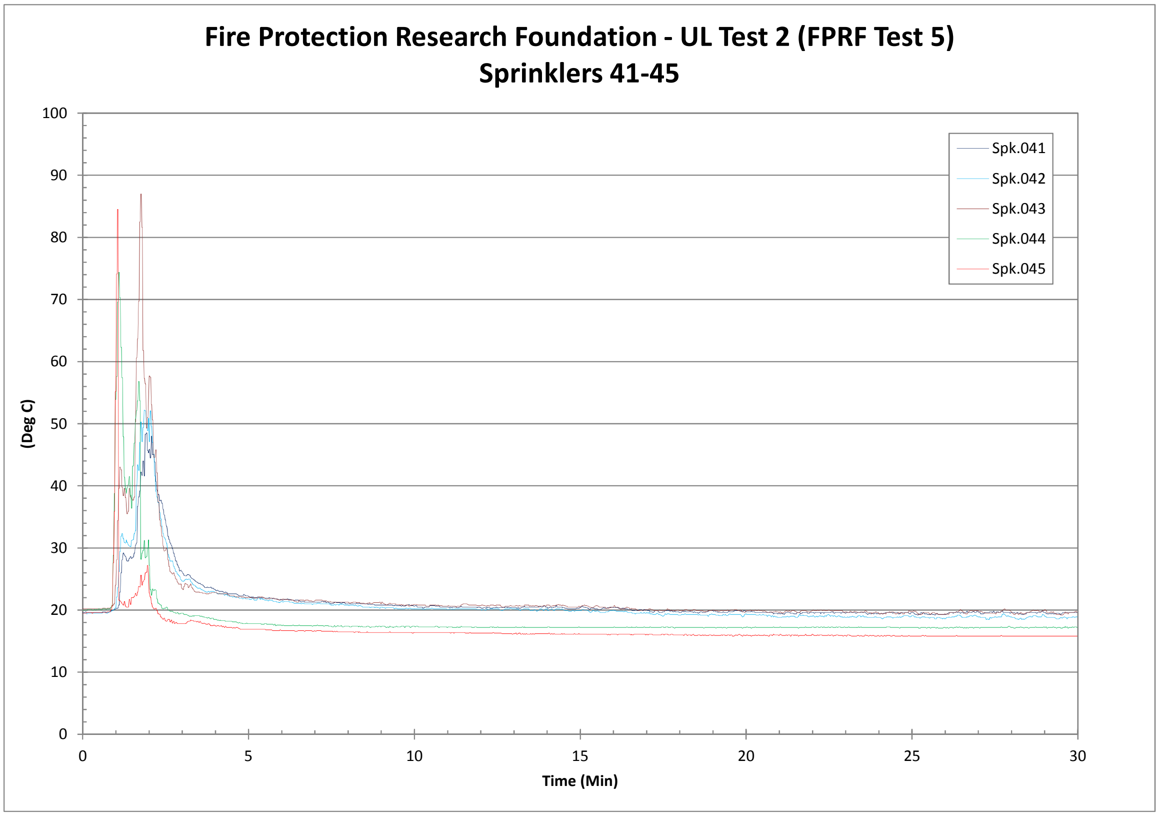

Fire Protection Research Foundation - UL Test 2 (FPRF Test 5)
Sprinklers 16-20
Spk.016
Spk.017
Spk.018
Spk.019
Spk.020
(Deg C)
Time (Min)
0
10
20
30
40
50
60
0
5
10
15
20
25
30

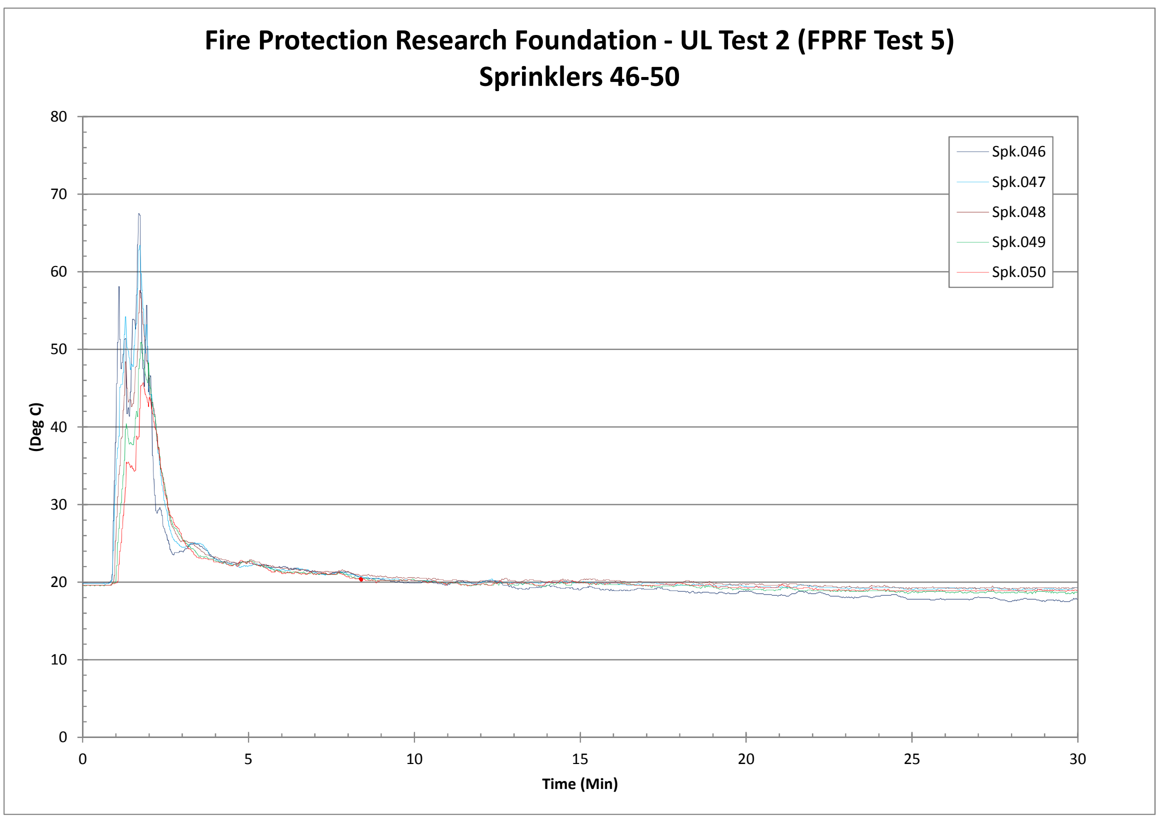

Fire Protection Research Foundation - UL Test 2 (FPRF Test 5)
Sprinklers 21-25
(Deg C)
Time (Min)
Spk.021
Spk.022
Spk.023
Spk.024
Spk.025
0
10
20
30
40
50
60
70
5
15
25

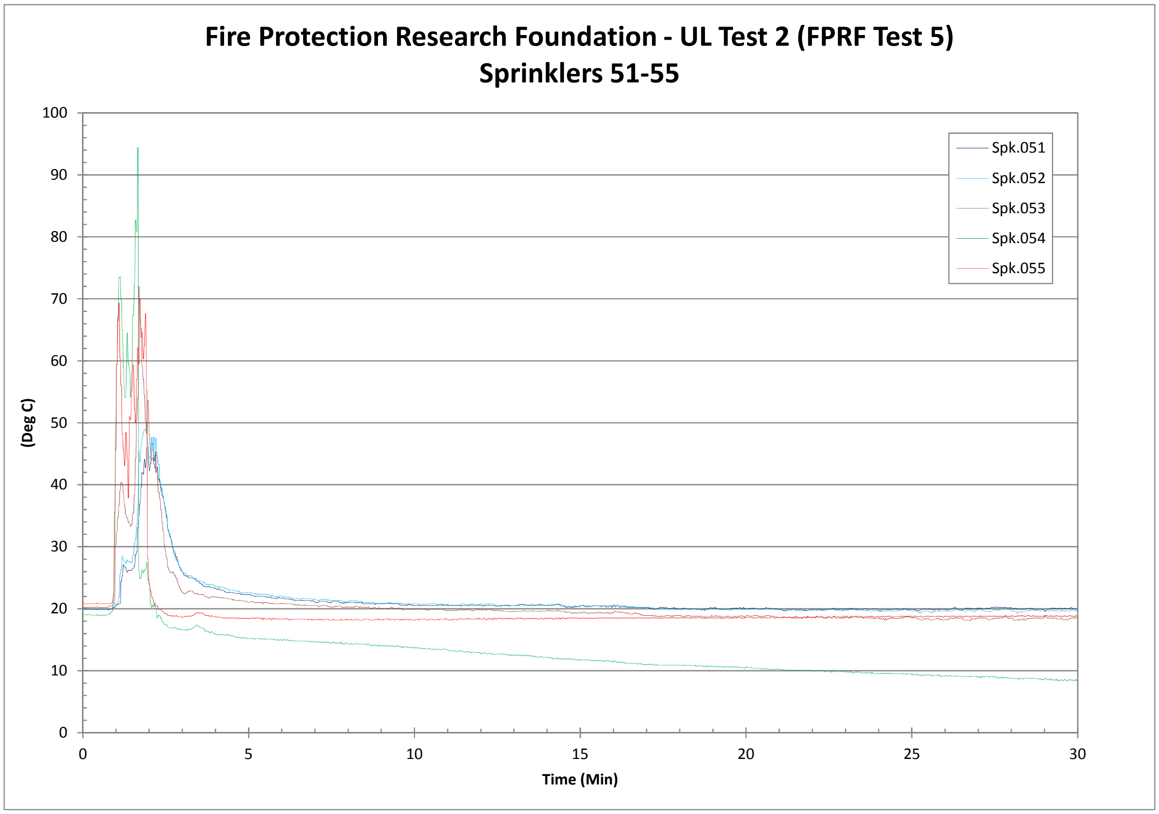

Fire Protection Research Foundation - UL Test 2 (FPRF Test 5)
Sprinklers 26-30
(Deg C)
Time (Min)
Spk.026
Spk.027
Spk.028
Spk.029
Spk.030
0
10
20
30
40
50
60
5
15
25

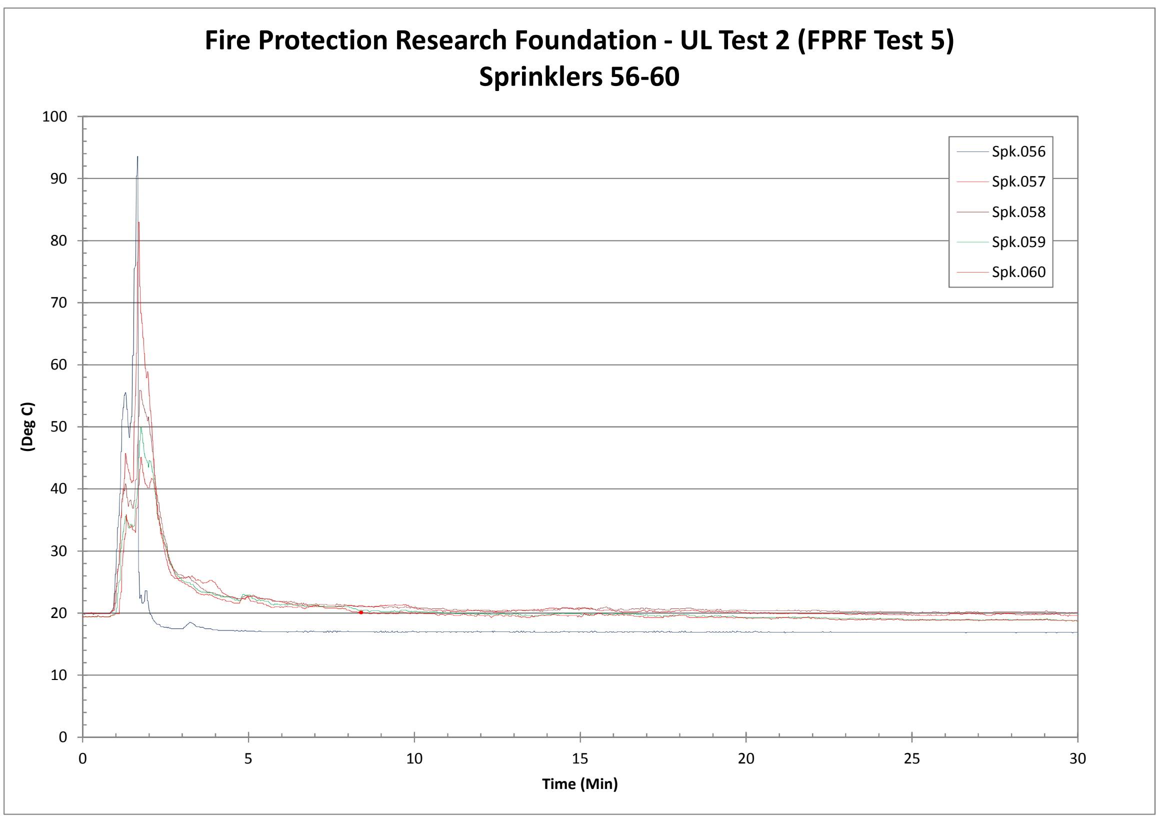

Fire Protection Research Foundation - UL Test 2 (FPRF Test 5)
Sprinklers 31-35
(Deg C)
Time (Min)
Spk.031
Spk.032
Spk.033
Spk.034
Spk.035
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
25
30

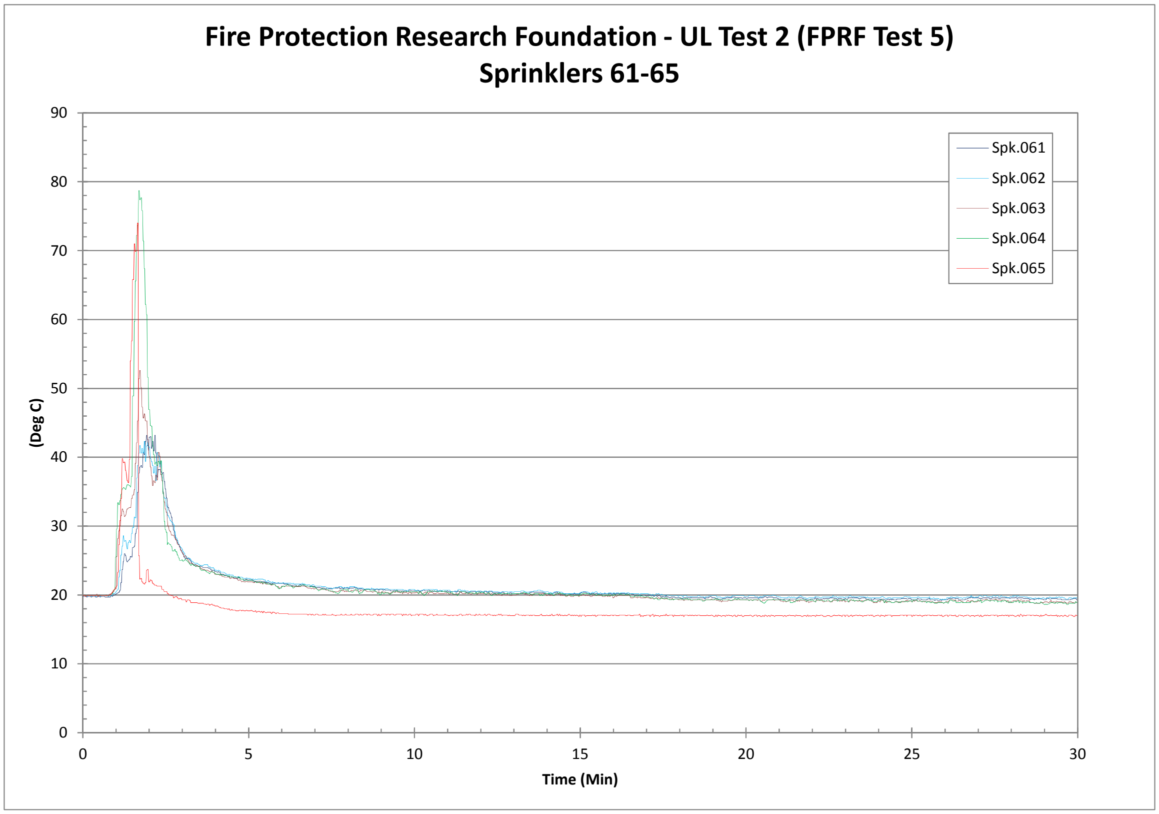

Fire Protection Research Foundation - UL Test 2 (FPRF Test 5)
Sprinklers 36-40
(Deg C)
Time (Min)
Spk.036
Spk.037
Spk.038
Spk.039
Spk.040
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30

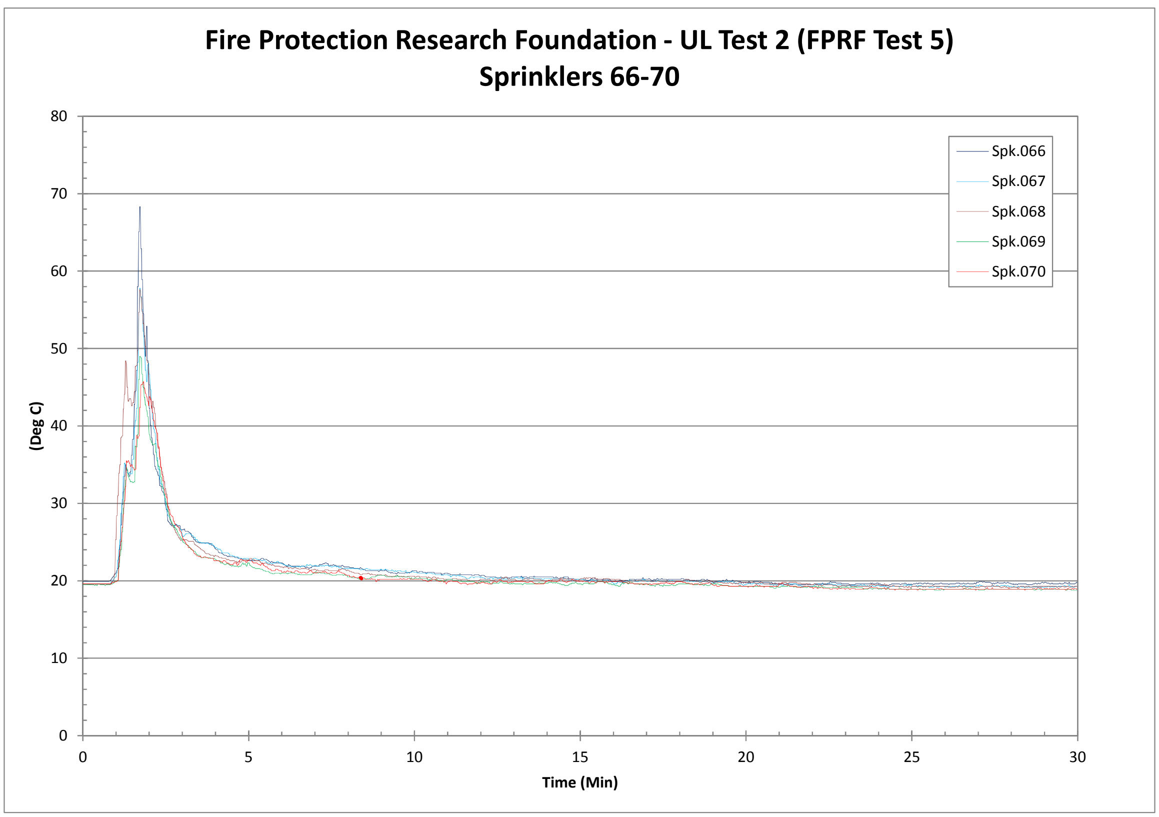

Fire Protection Research Foundation - UL Test 2 (FPRF Test 5)
Sprinklers 41-45
(Deg C)
Time (Min)
Spk.041
Spk.042
Spk.043
Spk.044
Spk.045
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
25
30

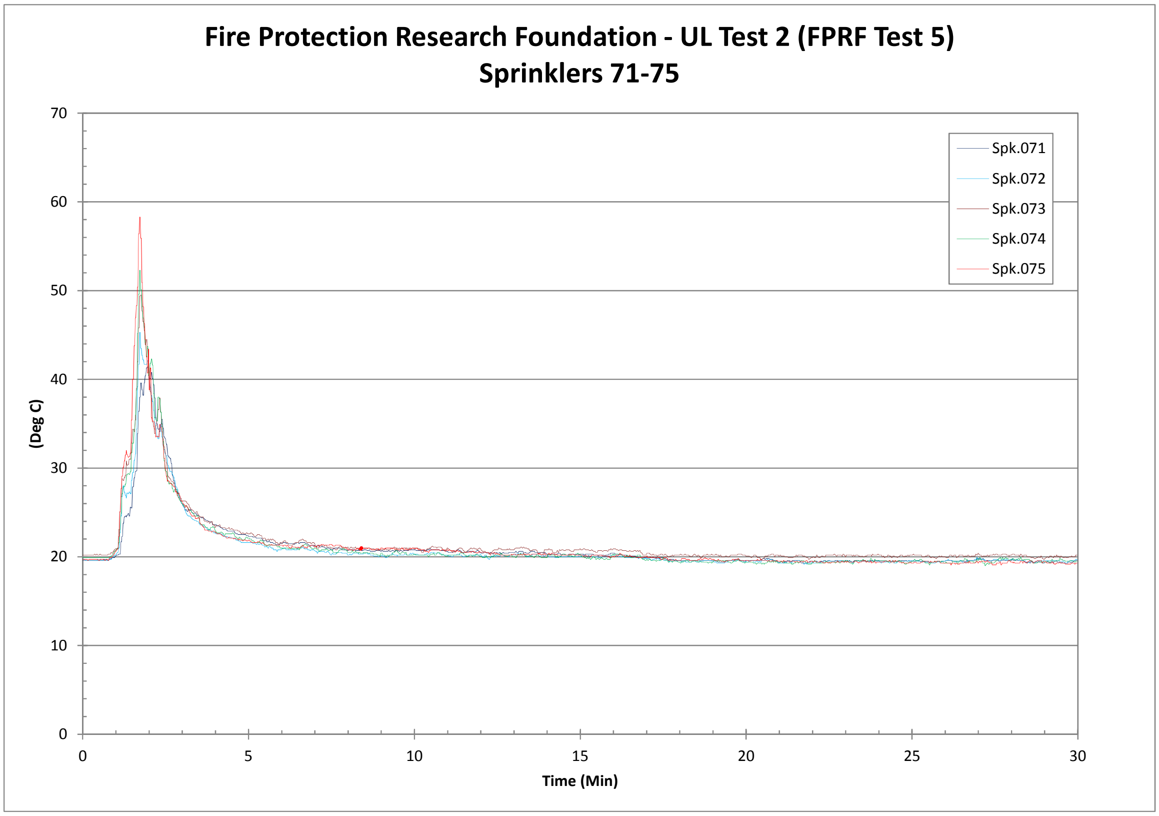

Fire Protection Research Foundation - UL Test 2 (FPRF Test 5)
Sprinklers 46-50
(Deg C)
Time (Min)
Spk.046
Spk.047
Spk.048
Spk.049
Spk.050
0
10
20
30
40
50
60
70
80
0
5
10
15
20
25
30

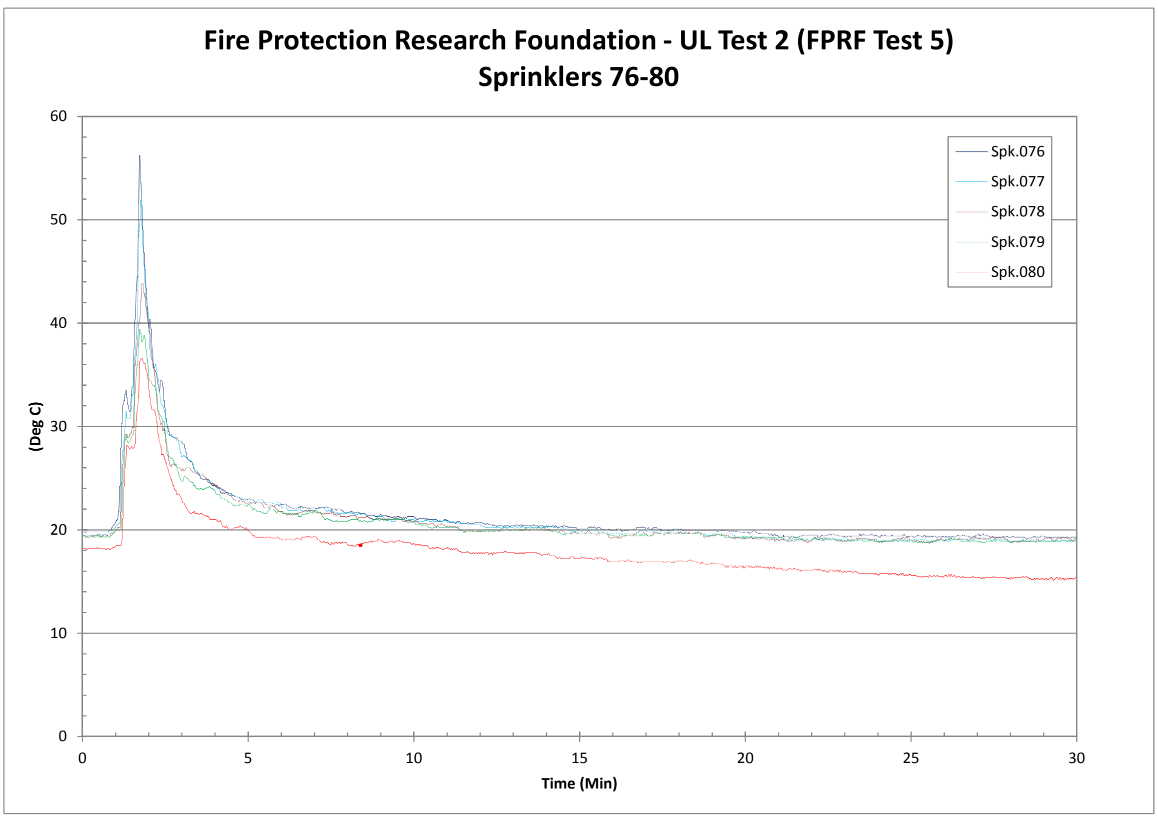

Fire Protection Research Foundation - UL Test 2 (FPRF Test 5)
Sprinklers 51-55
(Deg C)
Time (Min)
Spk.051
Spk.052
Spk.053
Spk.054
Spk.055
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
25
30

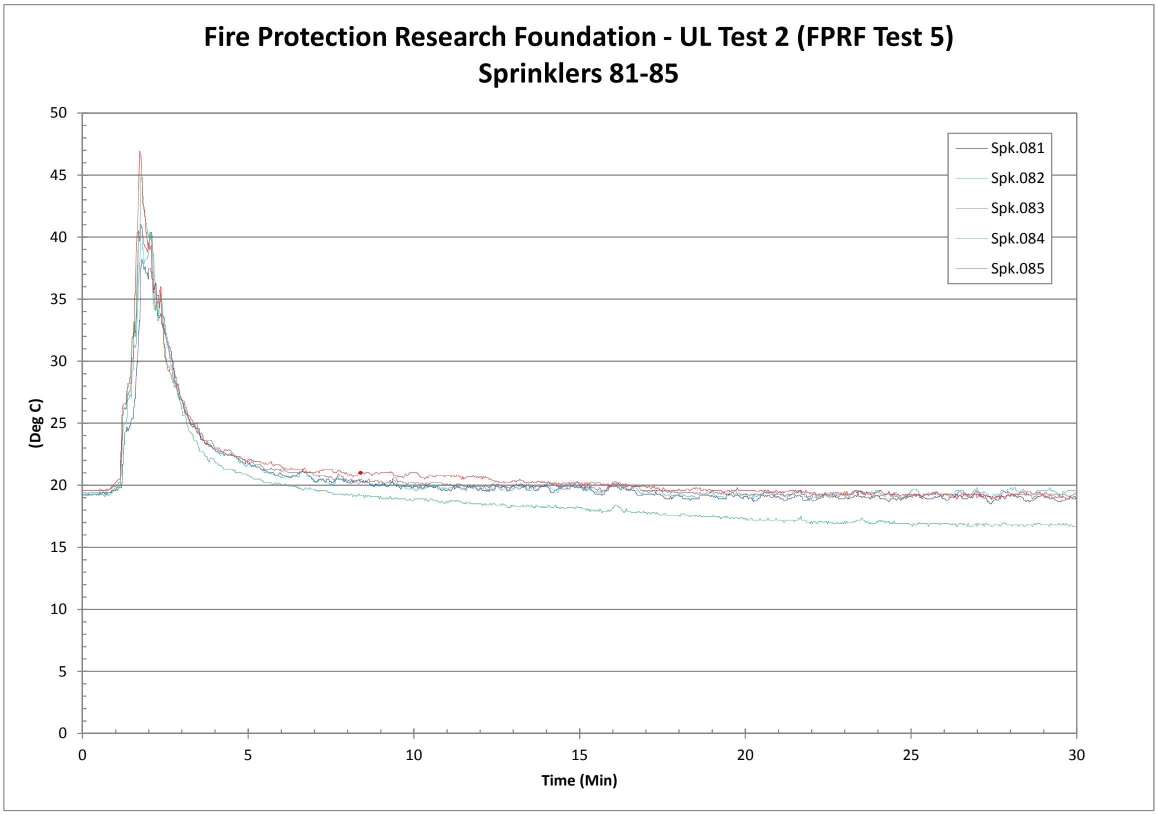

Fire Protection Research Foundation - UL Test 2 (FPRF Test 5)
Sprinklers 56-60
(Deg C)
Time (Min)
Spk.056
Spk.057
Spk.058
Spk.059
Spk.060
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
25
30

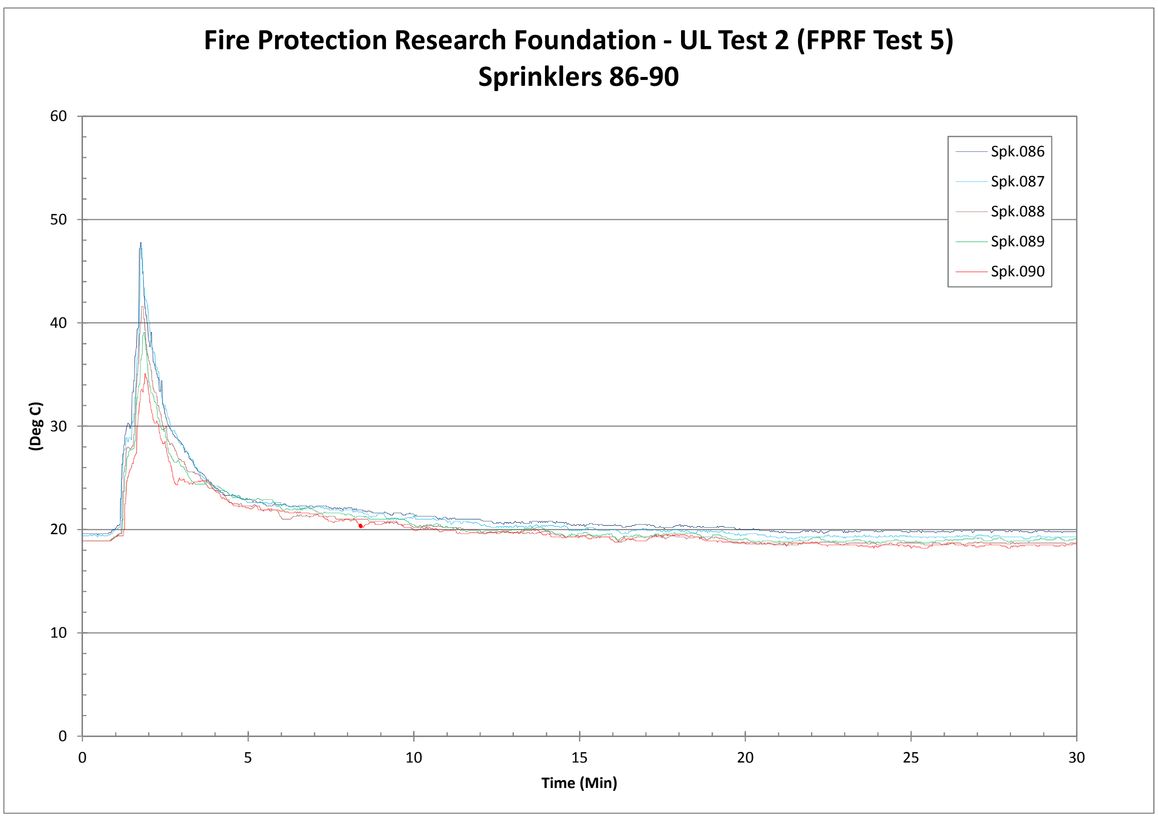

Fire Protection Research Foundation - UL Test 2 (FPRF Test 5)
Sprinklers 61-65
(Deg C)
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
Time (Min)
Spk.061
Spk.062
Spk.063
Spk.064
Spk.065

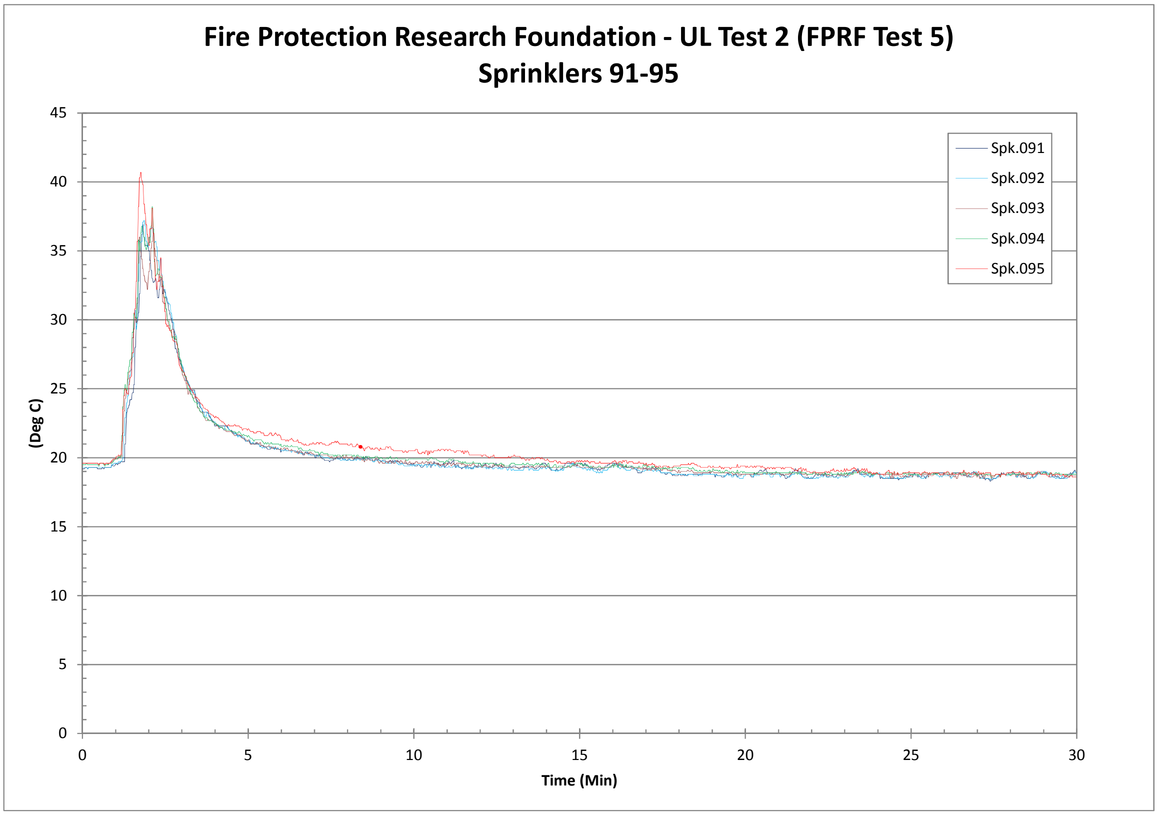

Fire Protection Research Foundation - UL Test 2 (FPRF Test 5)
Sprinklers 66-70
(Deg C)
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
Time (Min)
Spk.066
Spk.067
Spk.068
Spk.069
Spk.070

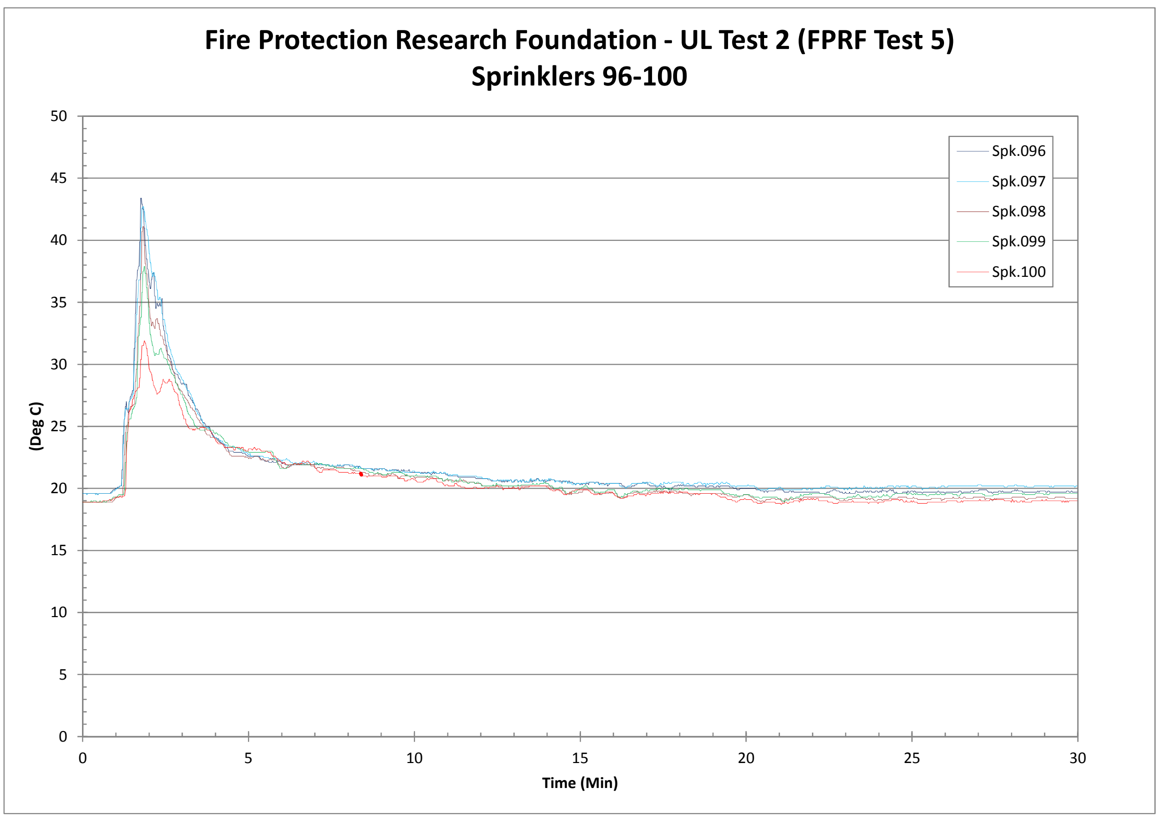

Fire Protection Research Foundation - UL Test 2 (FPRF Test 5)
Sprinklers 71-75
(Deg C)
Time (Min)
Spk.071
Spk.072
Spk.073
Spk.074
Spk.075
0
10
20
30
40
50
60
70
0
5
10
15
20
25
30

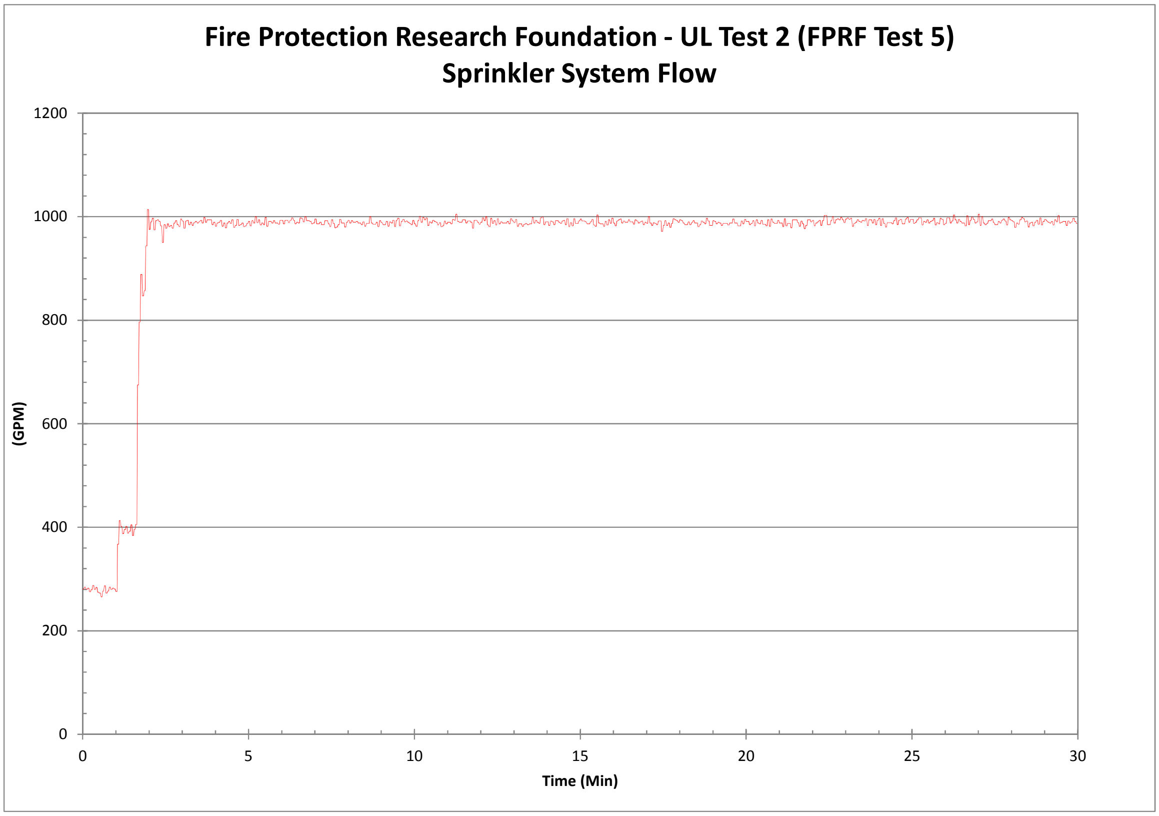

Fire Protection Research Foundation - UL Test 2 (FPRF Test 5)
Sprinklers 76-80
(Deg C)
Time (Min)
Spk.076
Spk.077
Spk.078
Spk.079
Spk.080
0
10
20
30
40
50
60
0
5
10
15
20
25
30

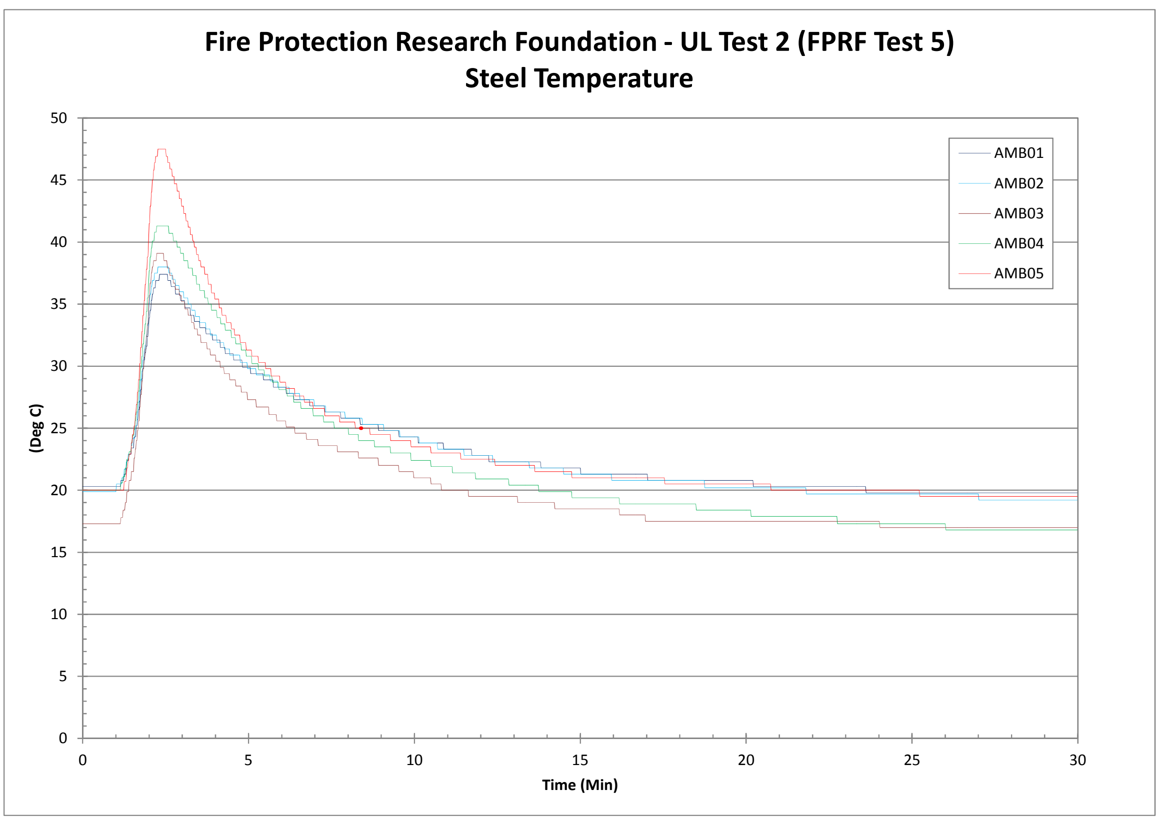

Fire Protection Research Foundation - UL Test 2 (FPRF Test 5)
Sprinklers 81-85
(Deg C)
Time (Min)
Spk.081
Spk.082
Spk.083
Spk.084
Spk.085
0
5
10
15
20
25
30
35
40
45
50
0
5
10
15
20
25
30

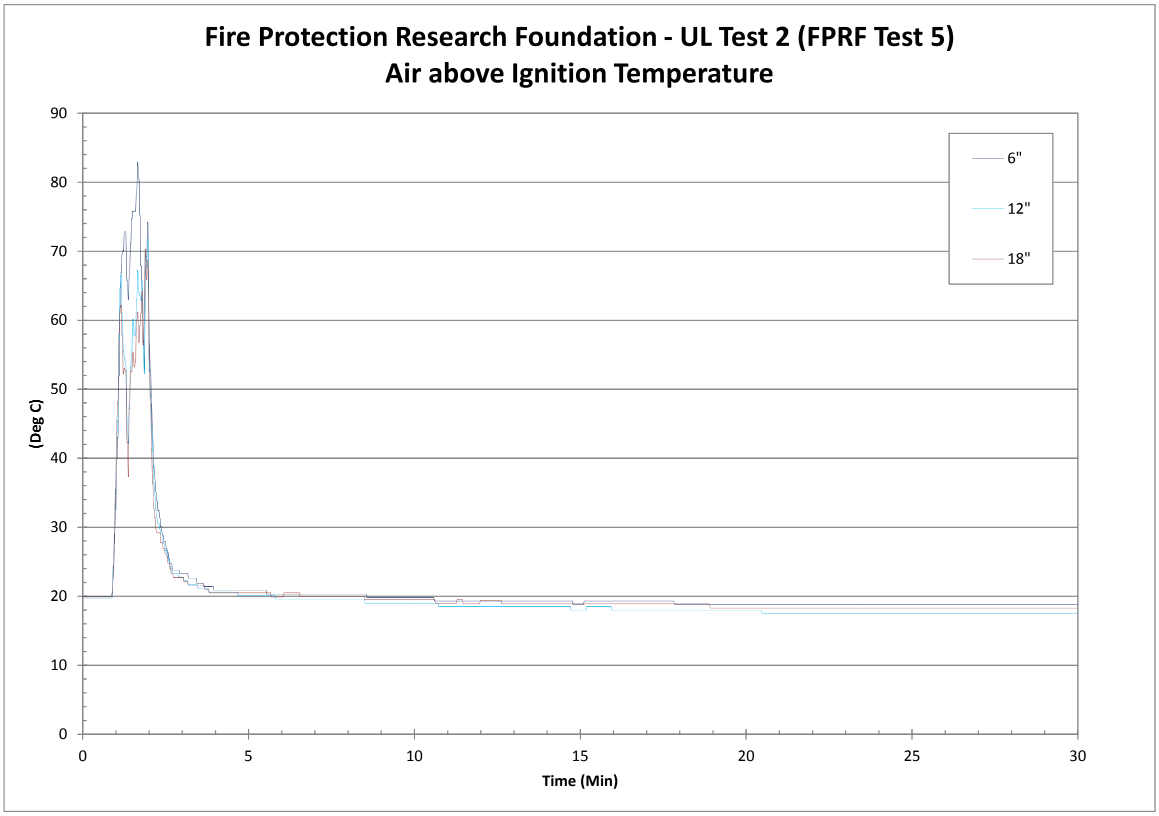

Fire Protection Research Foundation - UL Test 2 (FPRF Test 5)
Sprinklers 86-90
(Deg C)
Time (Min)
Spk.086
Spk.087
Spk.088
Spk.089
Spk.090
0
10
20
30
40
50
60
0
5
10
15
20
25
30

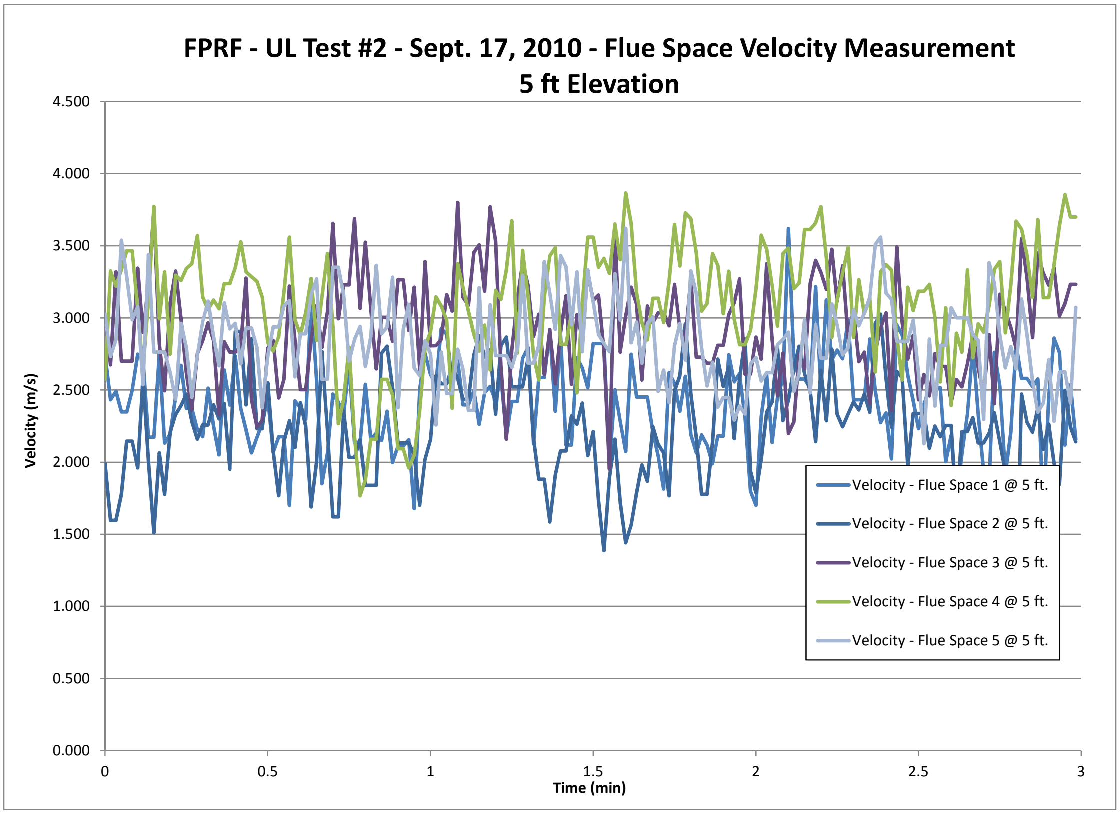

Fire Protection Research Foundation - UL Test 2 (FPRF Test 5)
Sprinklers 91-95
(Deg C)
Time (Min)
Spk.091
Spk.092
Spk.093
Spk.094
Spk.095
0
5
10
15
20
25
30
35
40
45

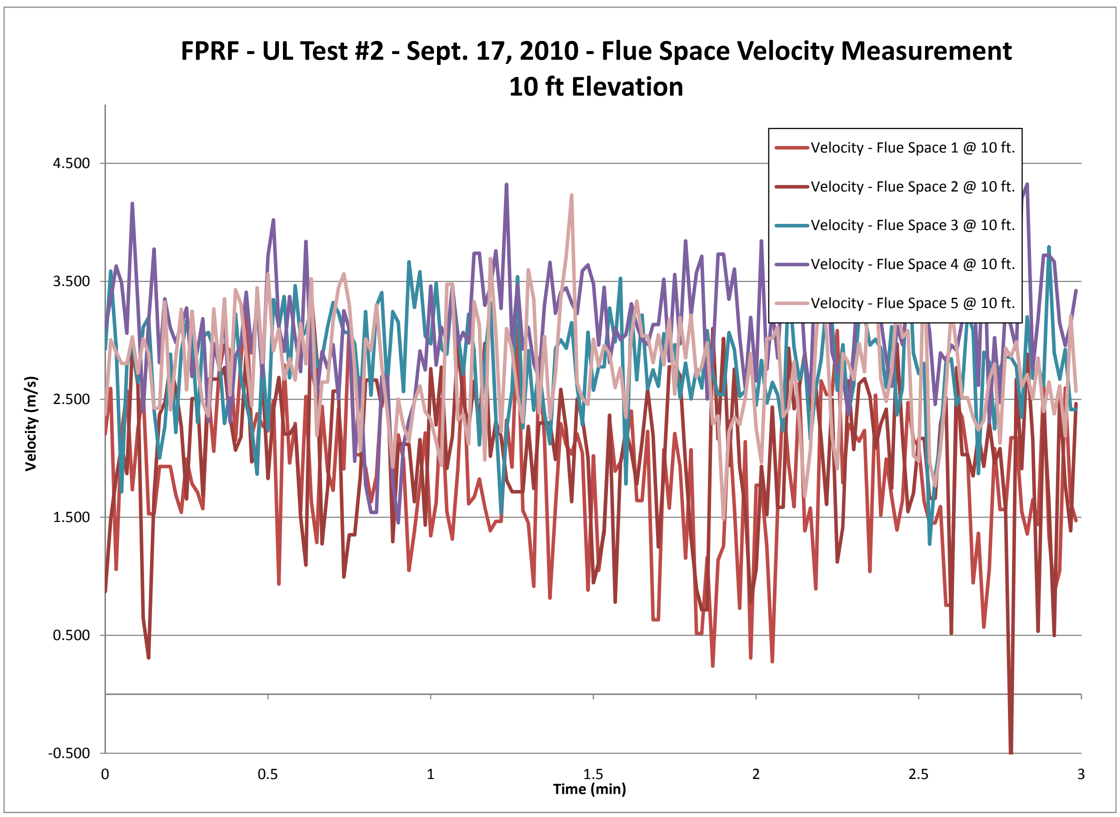

Fire Protection Research Foundation - UL Test 2 (FPRF Test 5)
Sprinklers 96-100
(Deg C)
Time (Min)
Spk.096
Spk.097
Spk.098
Spk.099
Spk.100
0
5
10
15
20
25
30
35
40
45
50

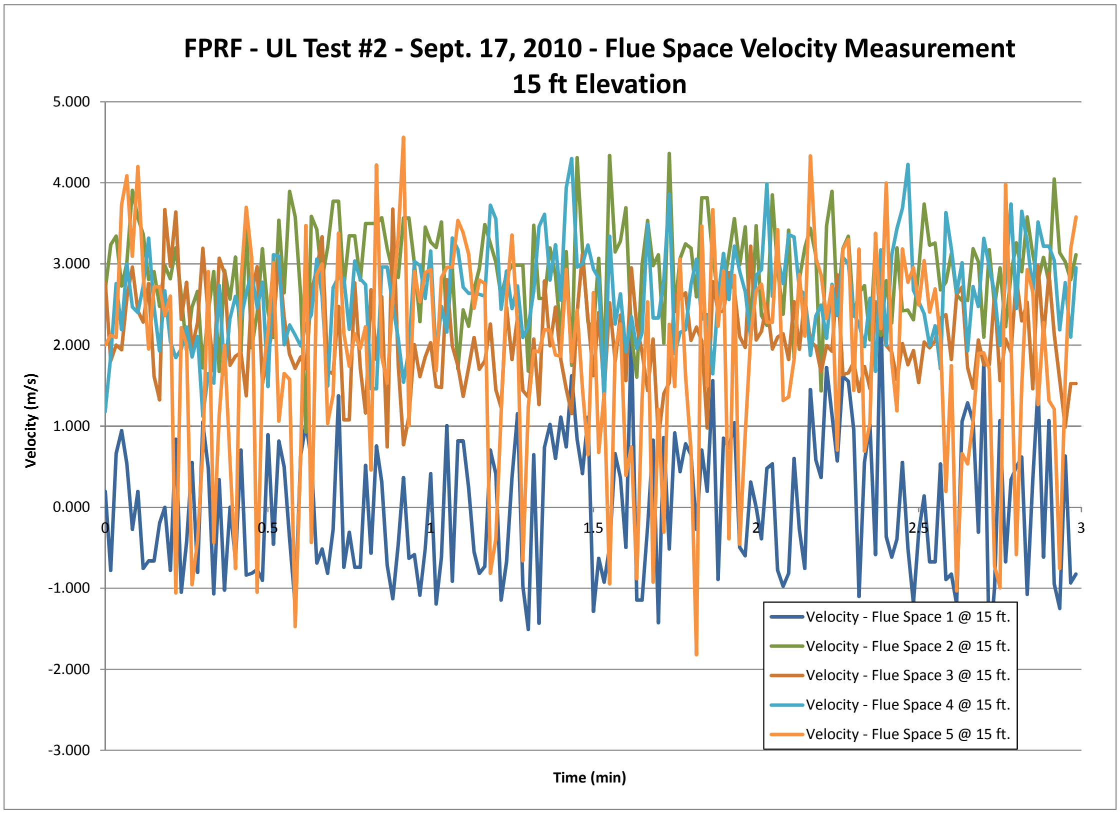

Fire Protection Research Foundation - UL Test 2 (FPRF Test 5)
Sprinkler System Flow
(GPM)
0
200
400
600
800
1000
1200
Time (Min)
0
5
10
15
20
25
30

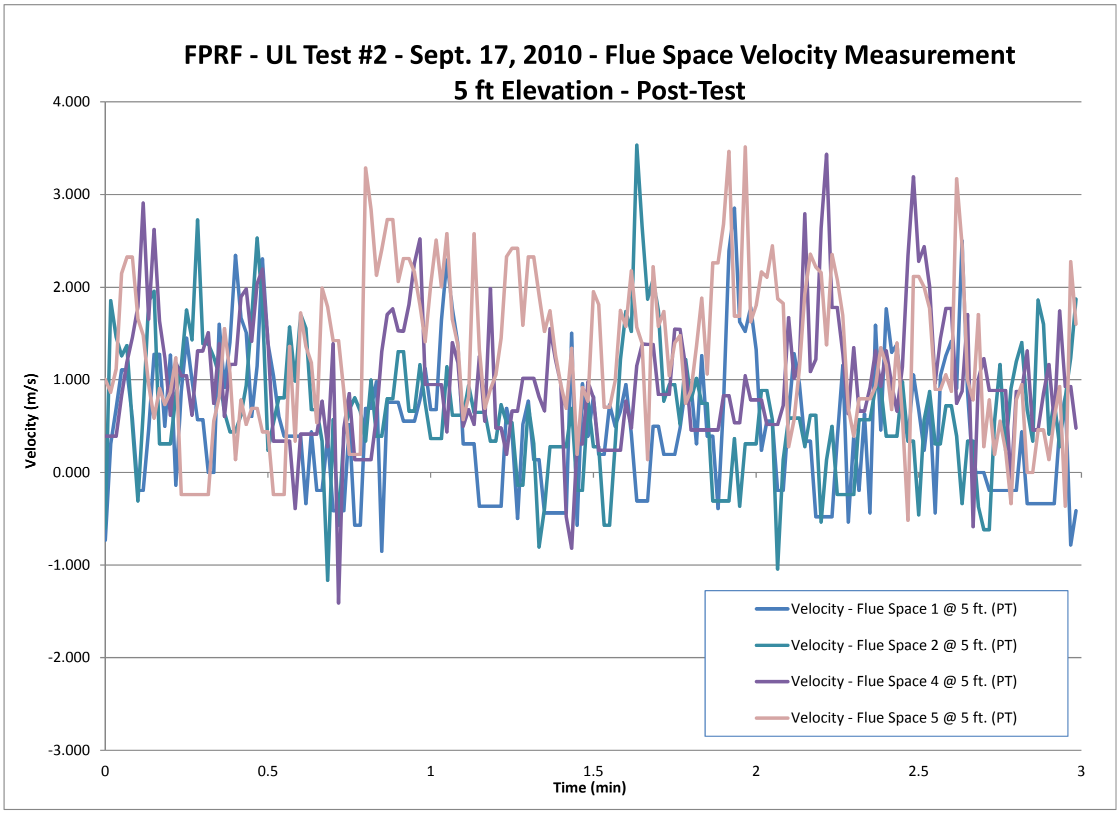

Fire Protection Research Foundation - UL Test 2 (FPRF Test 5)
Steel Temperature
(Deg C)
0
5
10
15
20
25
30
35
40
45
50
Time (Min)
0
5
10
15
20
25
30
AMB01
AMB02
AMB03
AMB04
AMB05

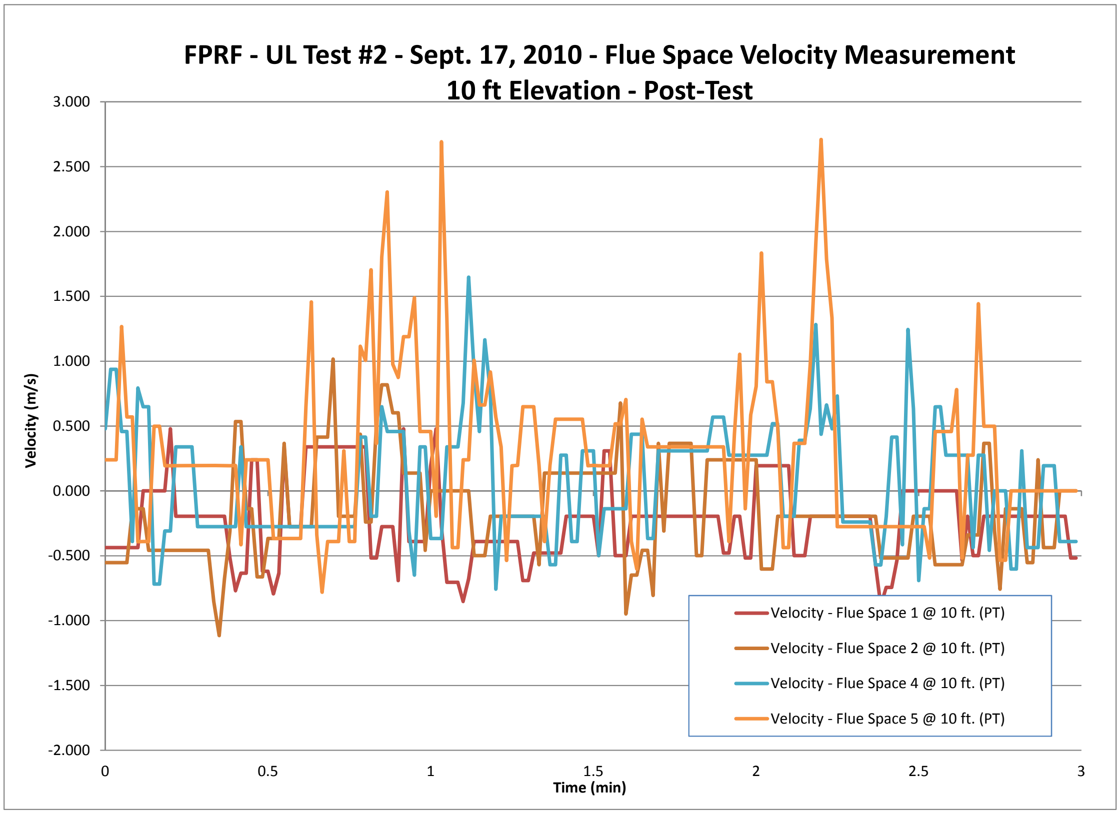

Fire Protection Research Foundation - UL Test 2 (FPRF Test 5)
Air above Ignition Temperature
(Deg C)
Time (Min)
6"
12"
18"
0
10
20
30
40
50
60
70
80
90
0
5
10
15
20
25
30

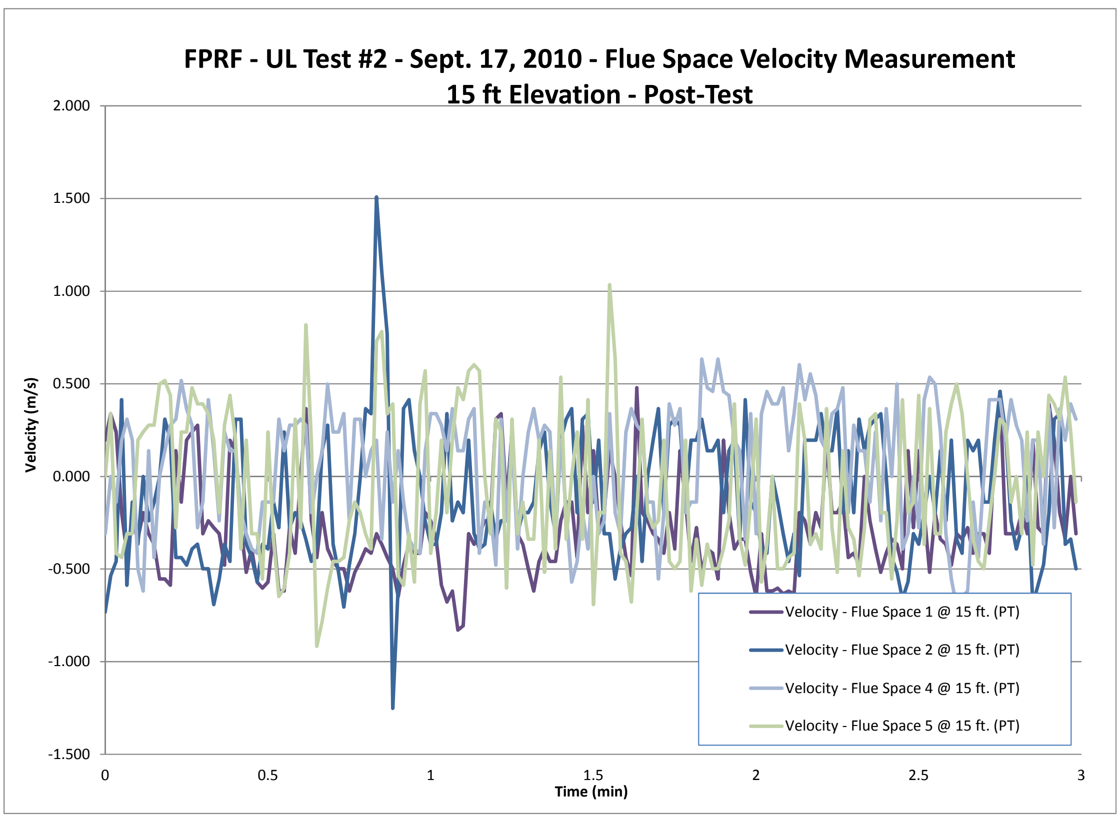

FPRF - UL Test #2 - Sept. 17, 2010 - Flue Space Velocity Measurement
5 ft Elevation
Velocity (m/s)
Time (min)
4.500
4.000
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
0
0.5
1
1.5
2
2.5
3
Velocity - Flue Space 1 @ 5 ft.
Velocity - Flue Space 2 @ 5 ft.
Velocity - Flue Space 3 @ 5 ft.
Velocity - Flue Space 4 @ 5 ft.
Velocity - Flue Space 5 @ 5 ft.


FPRF - UL Test #2 - Sept. 17, 2010 - Flue Space Velocity Measurement
10 ft Elevation
Velocity (m/s)
Time (min)
4.500
3.500
2.500
1.500
0.500
-0.500
0
0.5
1
1.5
2
2.5
3
Velocity - Flue Space 1 @ 10 ft.
Velocity - Flue Space 2 @ 10 ft.
Velocity - Flue Space 3 @ 10 ft.
Velocity - Flue Space 4 @ 10 ft.
Velocity - Flue Space 5 @ 10 ft.


FPRF - UL Test #2 - Sept. 17, 2010 - Flue Space Velocity Measurement
15 ft Elevation
Velocity (m/s)
Time (min)
5.000
4.000
3.000
2.000
1.000
0.000
-1.000
-2.000
-3.000
0
0.5
1
1.5
2
2.5
3
Velocity - Flue Space 1 @ 15 ft.
Velocity - Flue Space 2 @ 15 ft.
Velocity - Flue Space 3 @ 15 ft.
Velocity - Flue Space 4 @ 15 ft.
Velocity - Flue Space 5 @ 15 ft.


FPRF - UL Test #2 - Sept. 17, 2010 - Flue Space Velocity Measurement
5 ft Elevation - Post-Test
Velocity (m/s)
Time (min)
4.000
3.000
2.000
1.000
0.000
-1.000
-2.000
-3.000
0
0.5
1
1.5
2
2.5
3
Velocity - Flue Space 1 @ 5 ft. (PT)
Velocity - Flue Space 2 @ 5 ft. (PT)
Velocity - Flue Space 4 @ 5 ft. (PT)
Velocity - Flue Space 5 @ 5 ft. (PT)


FPRF - UL Test #2 - Sept. 17, 2010 - Flue Space Velocity Measurement
10 ft Elevation - Post-Test
Velocity (m/s)
3.000
2.500
2.000
1.500
1.000
0.500
0.000
-0.500
-1.000
-1.500
-2.000
0
0.5
1
1.5
2
2.5
3
Time (min)
Velocity - Flue Space 1 @ 10 ft. (PT)
Velocity - Flue Space 2 @ 10 ft. (PT)
Velocity - Flue Space 4 @ 10 ft. (PT)
Velocity - Flue Space 5 @ 10 ft. (PT)

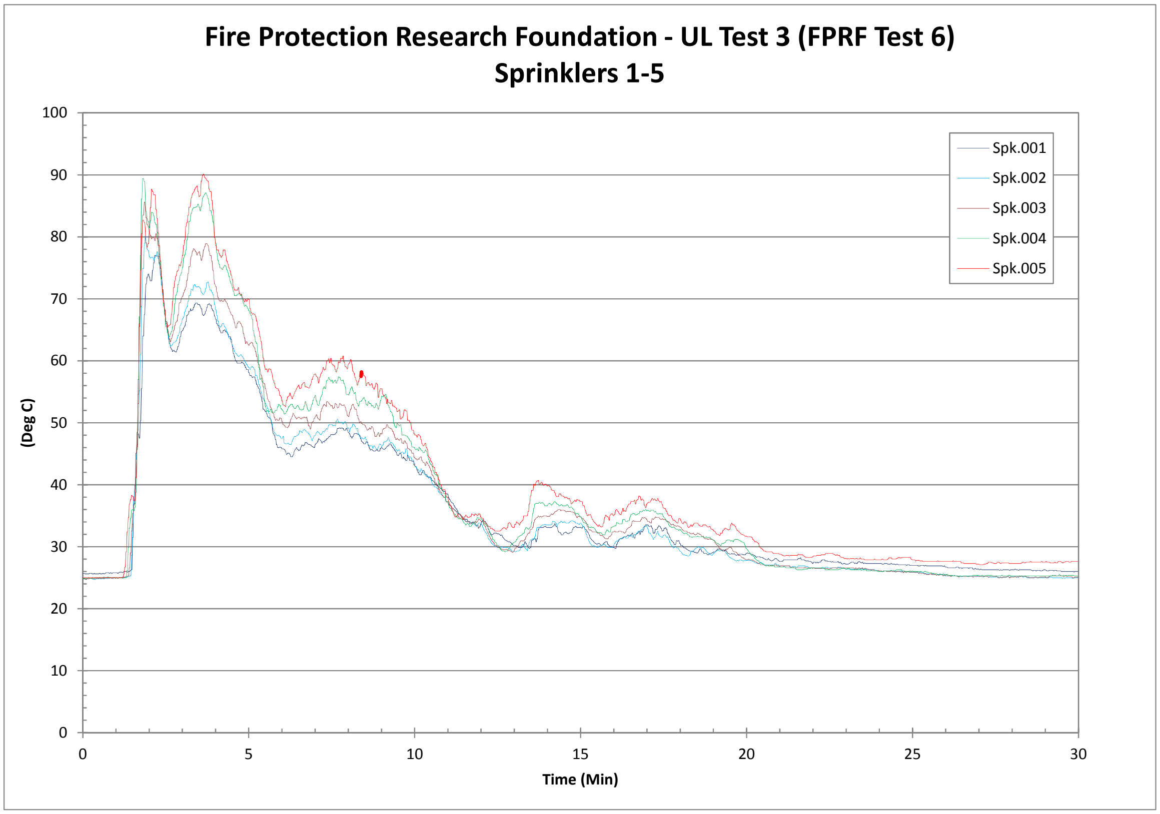

FPRF - UL Test #2 - Sept. 17, 2010 - Flue Space Velocity Measurement
15 ft Elevation - Post-Test
Velocity (m/s)
2.000
1.500
1.000
0.500
0.000
-0.500
-1.000
-1.500
0
0.5
1
1.5
2
2.5
3
Time (min)
Velocity - Flue Space 1 @ 15 ft. (PT)
Velocity - Flue Space 2 @ 15 ft. (PT)
Velocity - Flue Space 4 @ 15 ft. (PT)
Velocity - Flue Space 5 @ 15 ft. (PT)

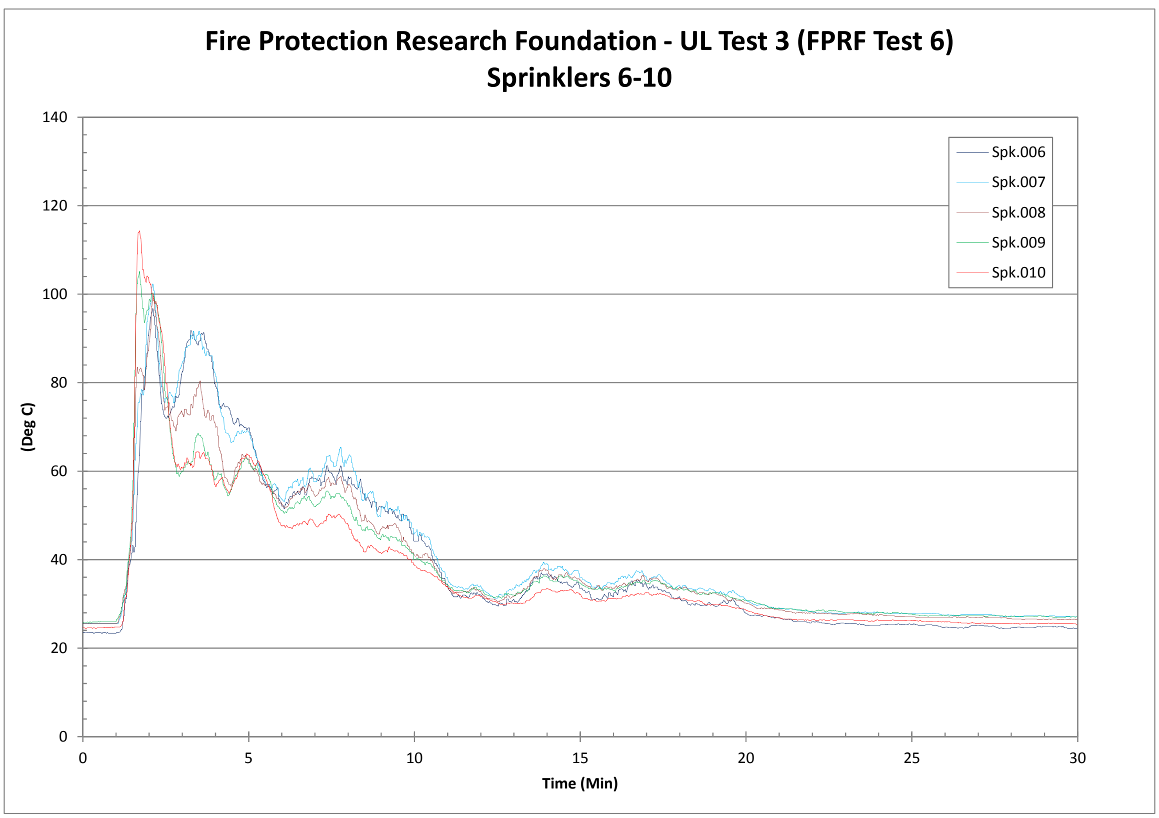
APPENDIX C

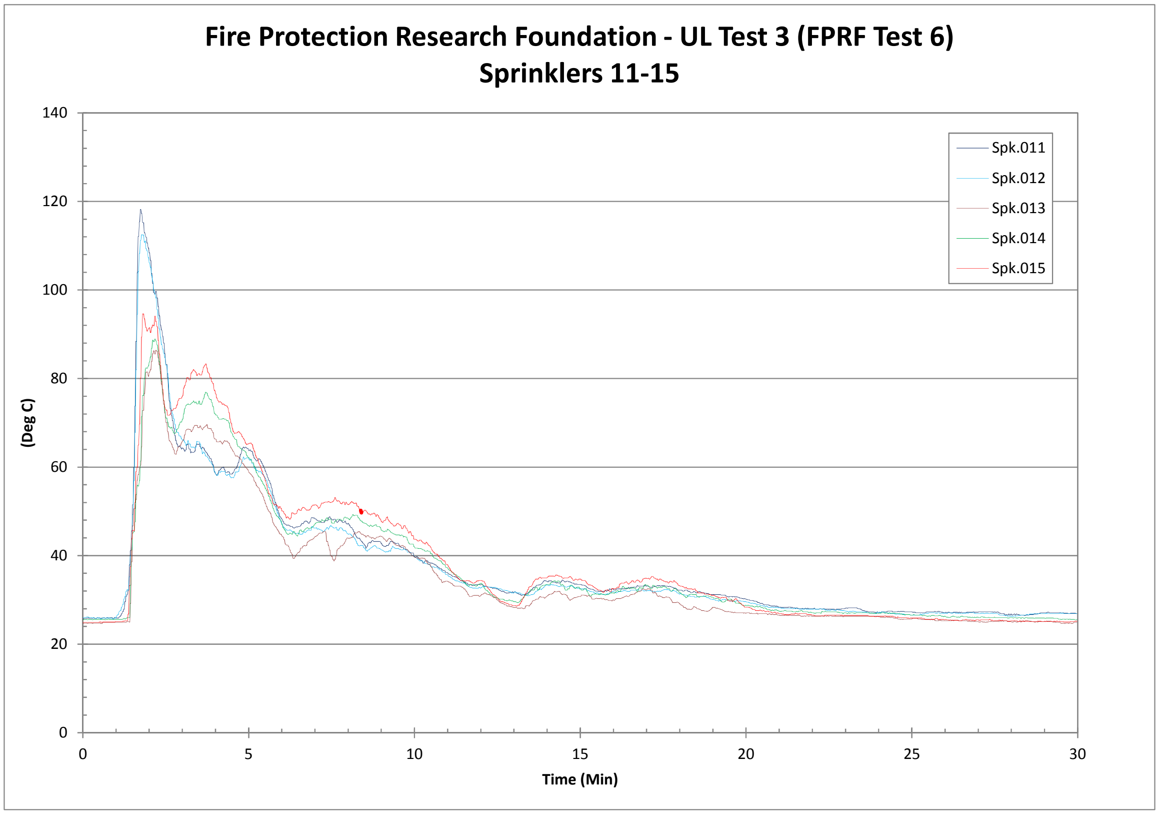
Graphical Presentation of

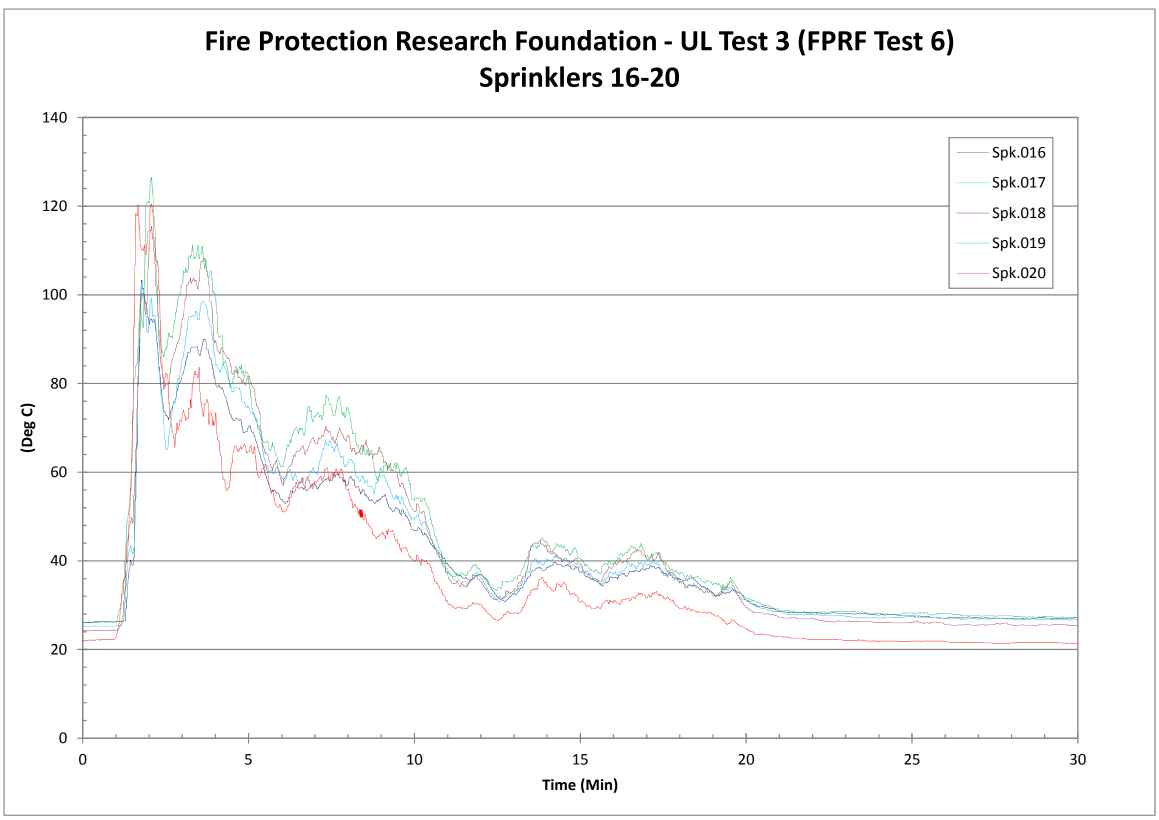
Gas Temperatures, Steel Temperatures, System Waterflow and Velocities - Test 3

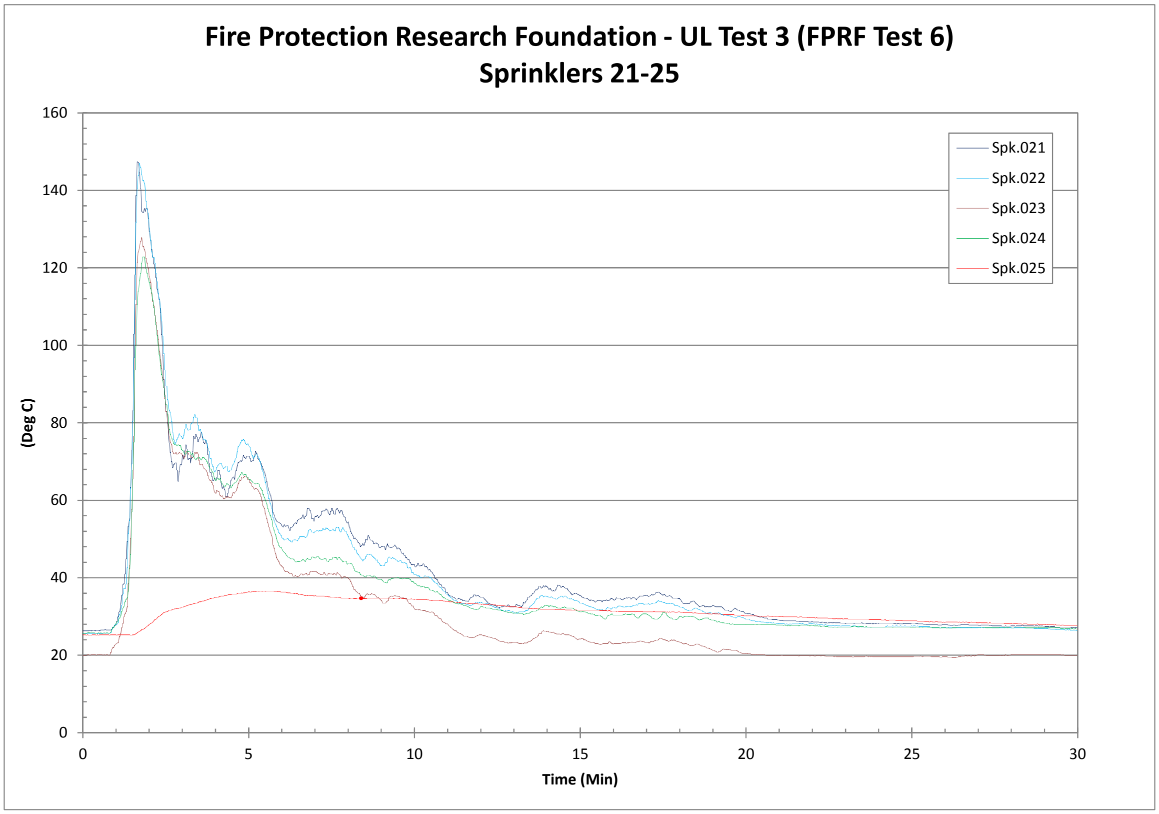
Index:	Page

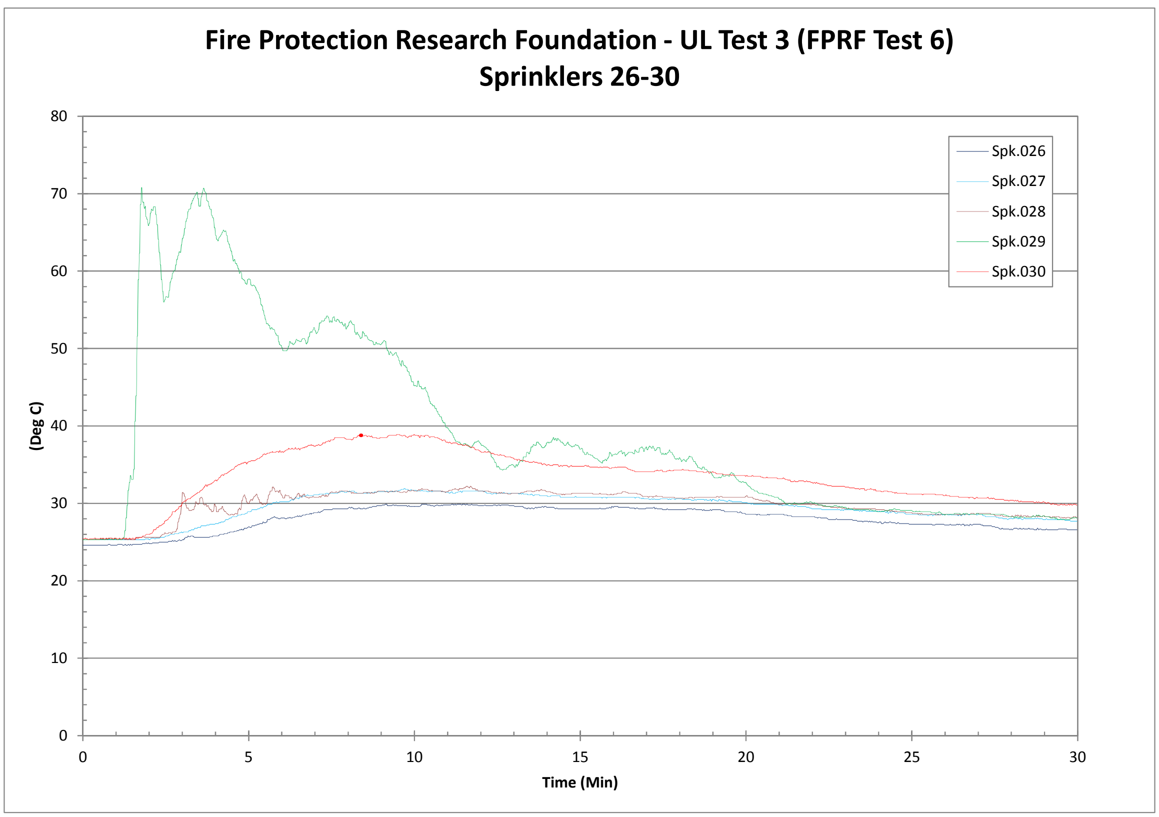

Fire Protection Research Foundation - UL Test 3 (FPRF Test 6)
Sprinklers 1-5
(Deg C)
Time (Min)
Spk.001
Spk.002
Spk.003
Spk.004
Spk.005
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
25
30

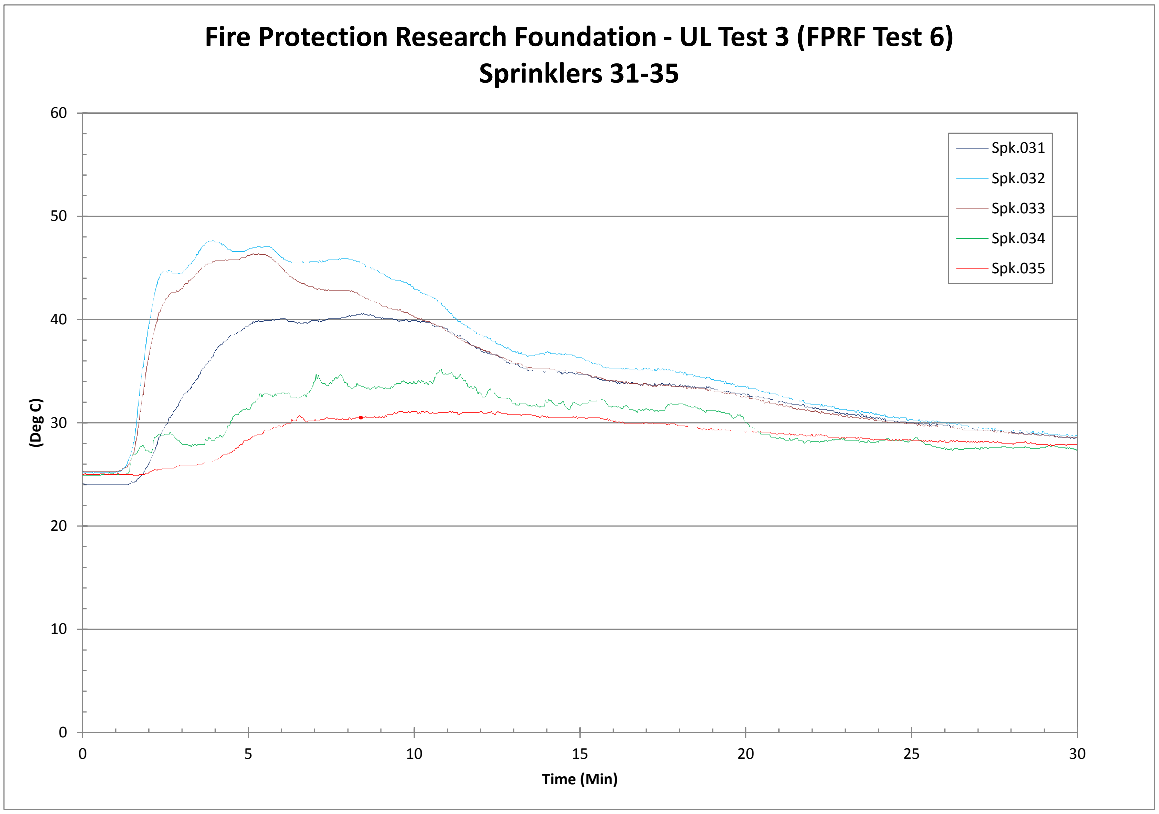

Fire Protection Research Foundation - UL Test 3 (FPRF Test 6)
Sprinklers 6-10
(Deg C)
Time (Min)
Spk.006
Spk.007
Spk.008
Spk.009
Spk.010
0
20
40
60
80
100
120
140
0
5
10
15
20
25
30

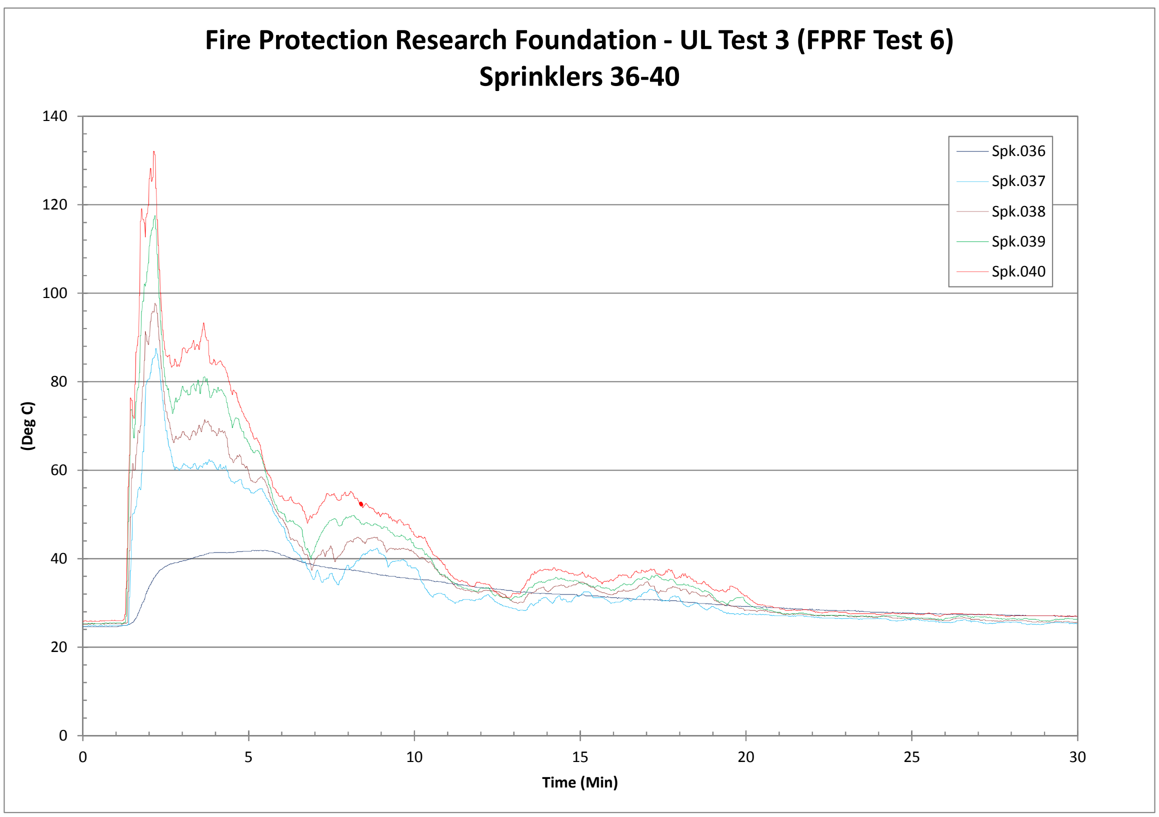

Fire Protection Research Foundation - UL Test 3 (FPRF Test 6)
Sprinklers 11-15
(Deg C)
Time (Min)
Spk.011
Spk.012
Spk.013
Spk.014
Spk.015
0
20
40
60
80
100
120
140
0
5
10
15
20
25
30

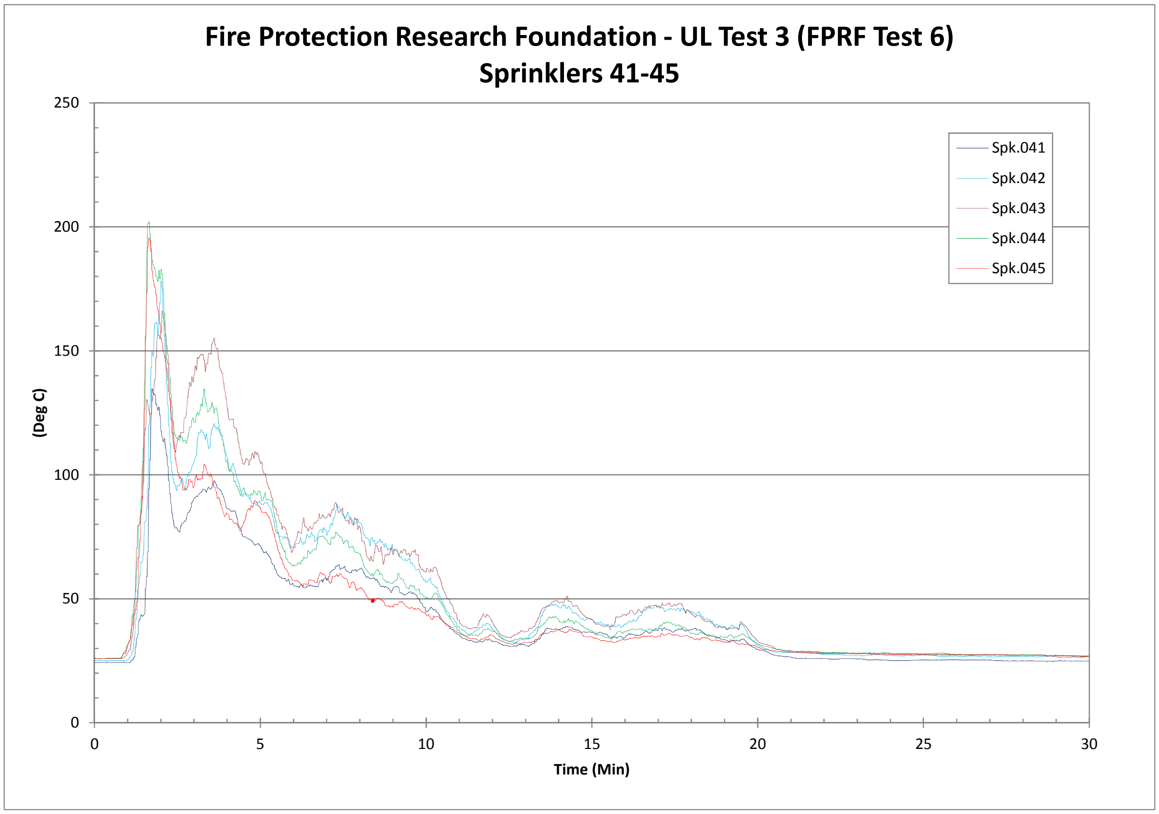

Fire Protection Research Foundation - UL Test 3 (FPRF Test 6)
Sprinklers 16-20
(Deg C)
Time (Min)
Spk.016
Spk.017
Spk.018
Spk.019
Spk.020
0
20
40
60
80
100
120
140
0
5
10
15
20
25
30

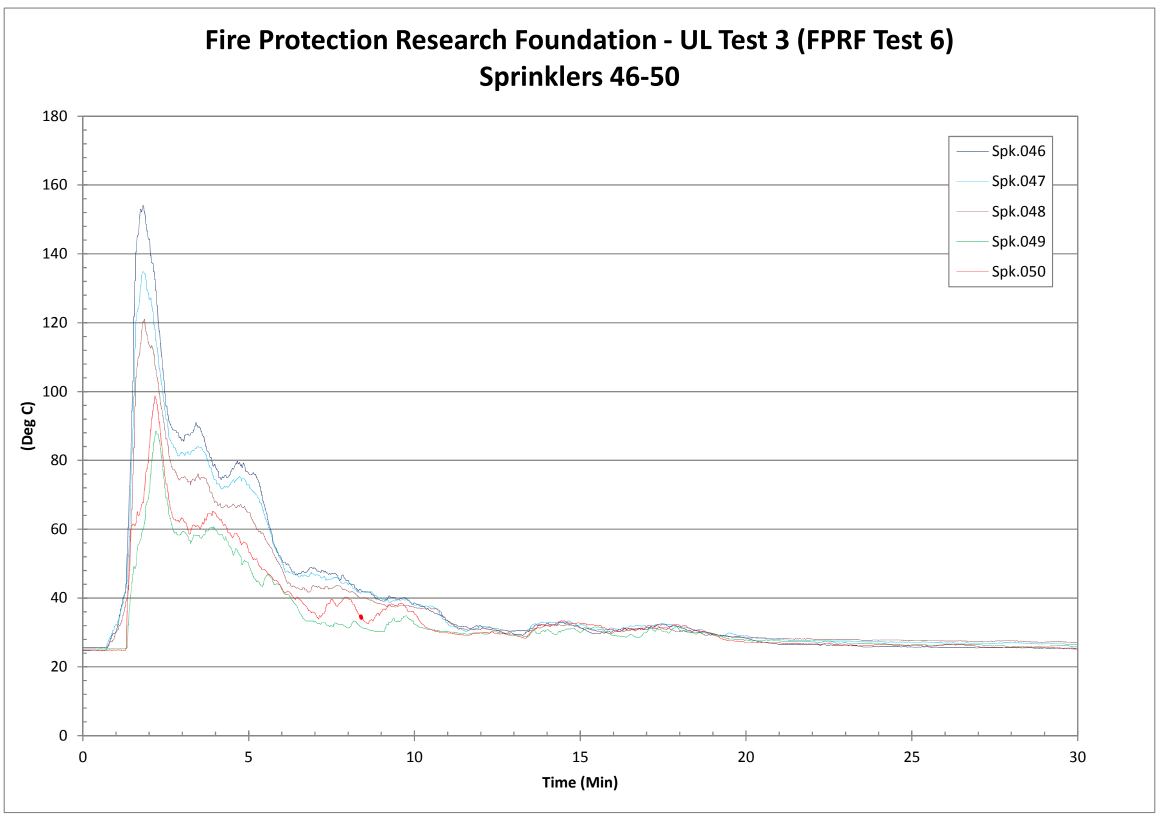

Fire Protection Research Foundation - UL Test 3 (FPRF Test 6)
Sprinklers 21-25
(Deg C)
160
140
120
100
80
60
40
20
0
0
5
10
15
20
25
30
Time (Min)
Spk.021
Spk.022
Spk.023
Spk.024
Spk.025

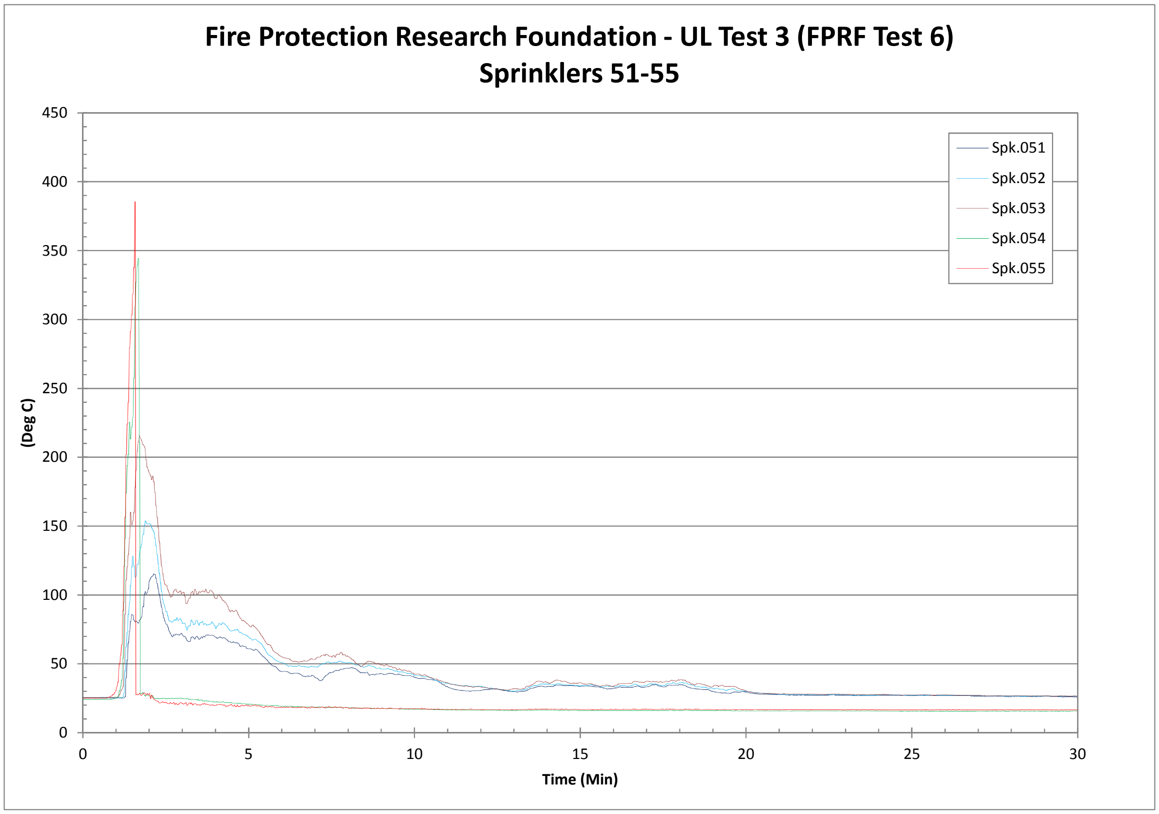

Fire Protection Research Foundation - UL Test 3 (FPRF Test 6)
Sprinklers 26-30
(Deg C)
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
Time (Min)
Spk.026
Spk.027
Spk.028
Spk.029
Spk.030

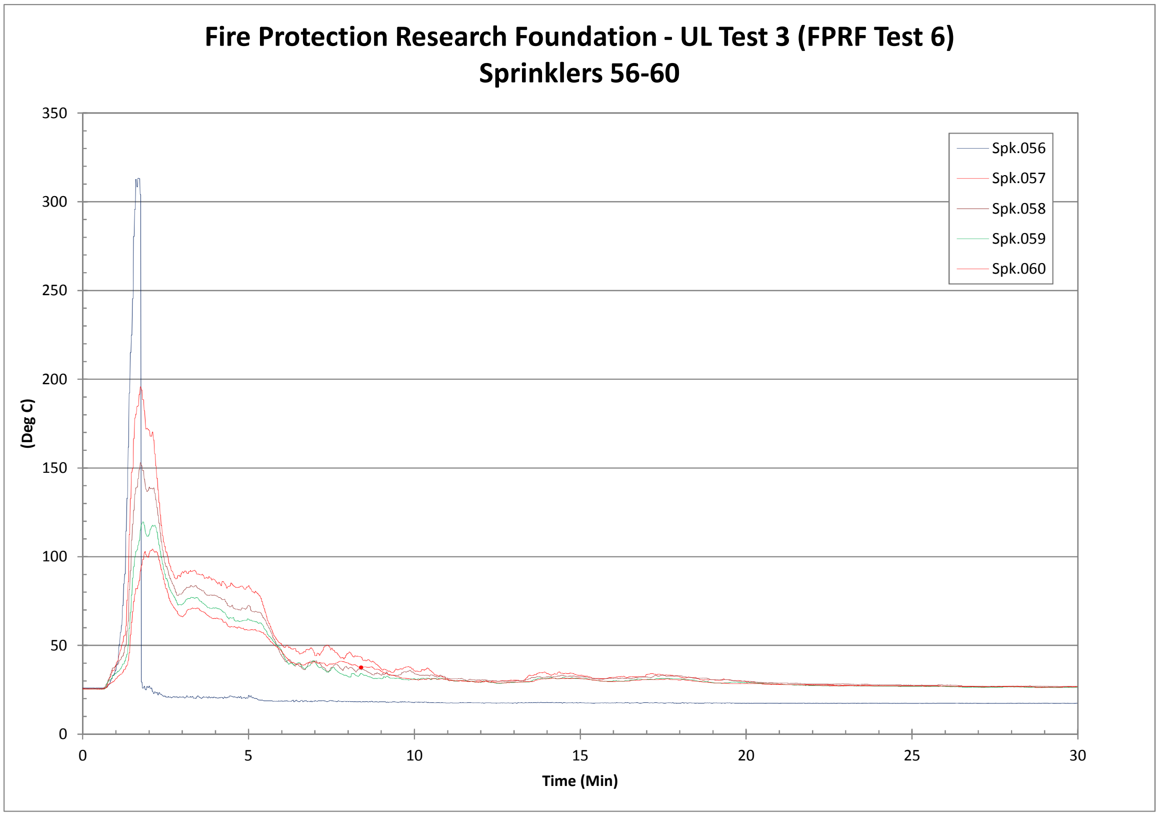

Fire Protection Research Foundation - UL Test 3 (FPRF Test 6)
Sprinklers 31-35
(Deg C)
Time (Min)
Spk.031
Spk.032
Spk.033
Spk.034
Spk.035
0
10
20
30
40
50
60
0
5
10
15
20
25
30

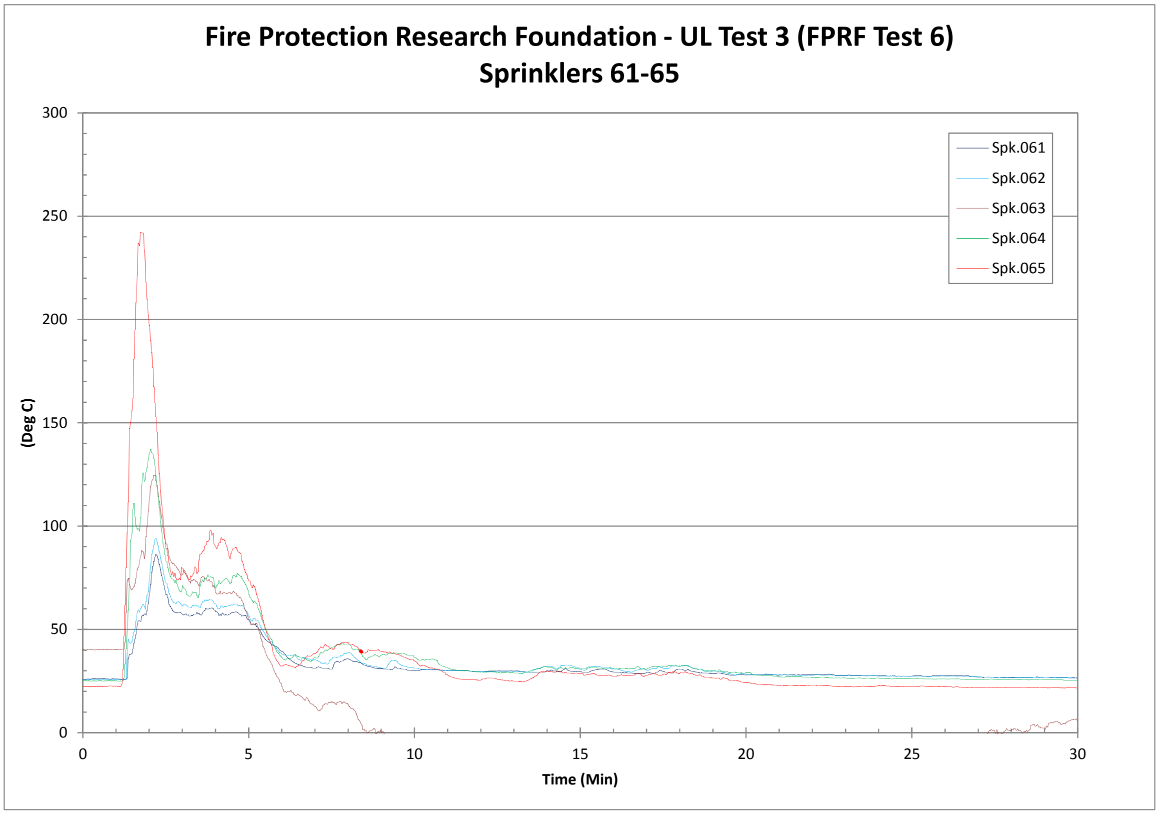

Fire Protection Research Foundation - UL Test 3 (FPRF Test 6)
Sprinklers 36-40
(Deg C)
Time (Min)
Spk.036
Spk.037
Spk.038
Spk.039
Spk.040
0
20
40
60
80
100
120
140
0
5
10
15
20
25
30

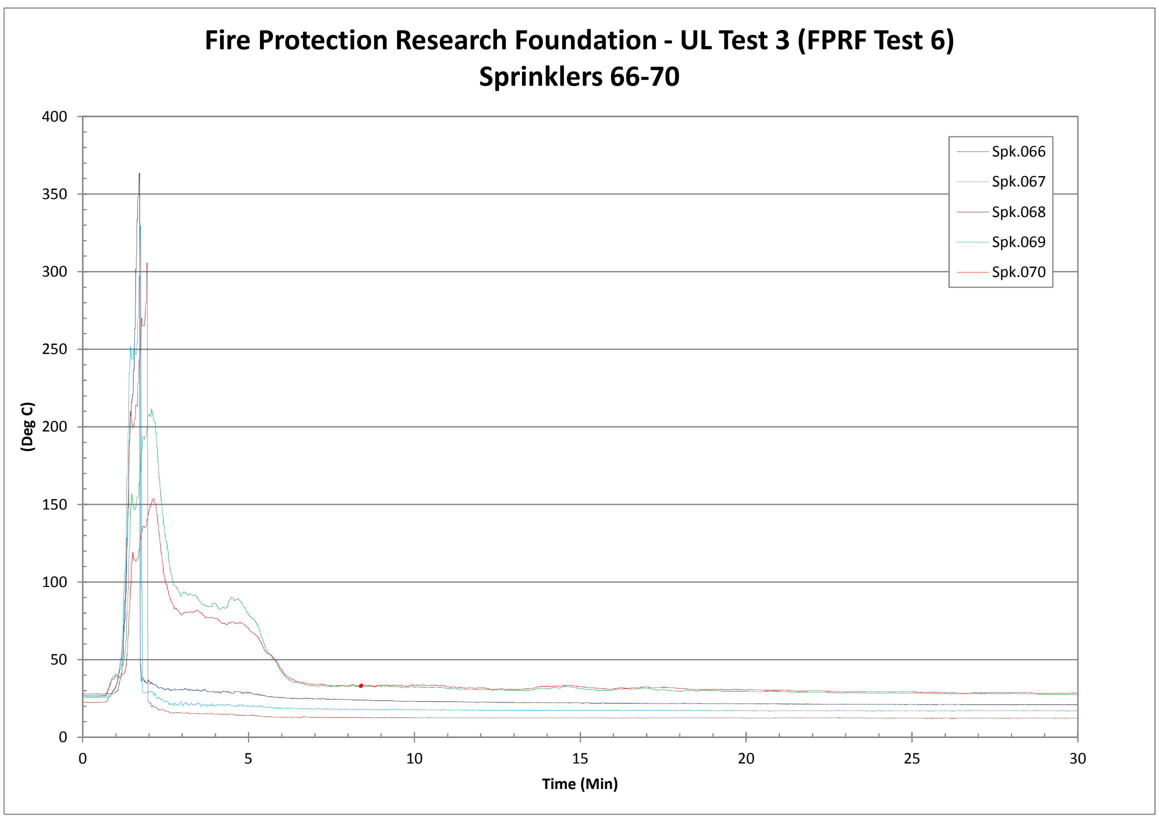

Fire Protection Research Foundation - UL Test 3 (FPRF Test 6)
Sprinklers 41-45
(Deg C)
Time (Min)
Spk.041
Spk.042
Spk.043
Spk.044
Spk.045
0
50
100
150
200
250
0
5
10
15
20
25
30

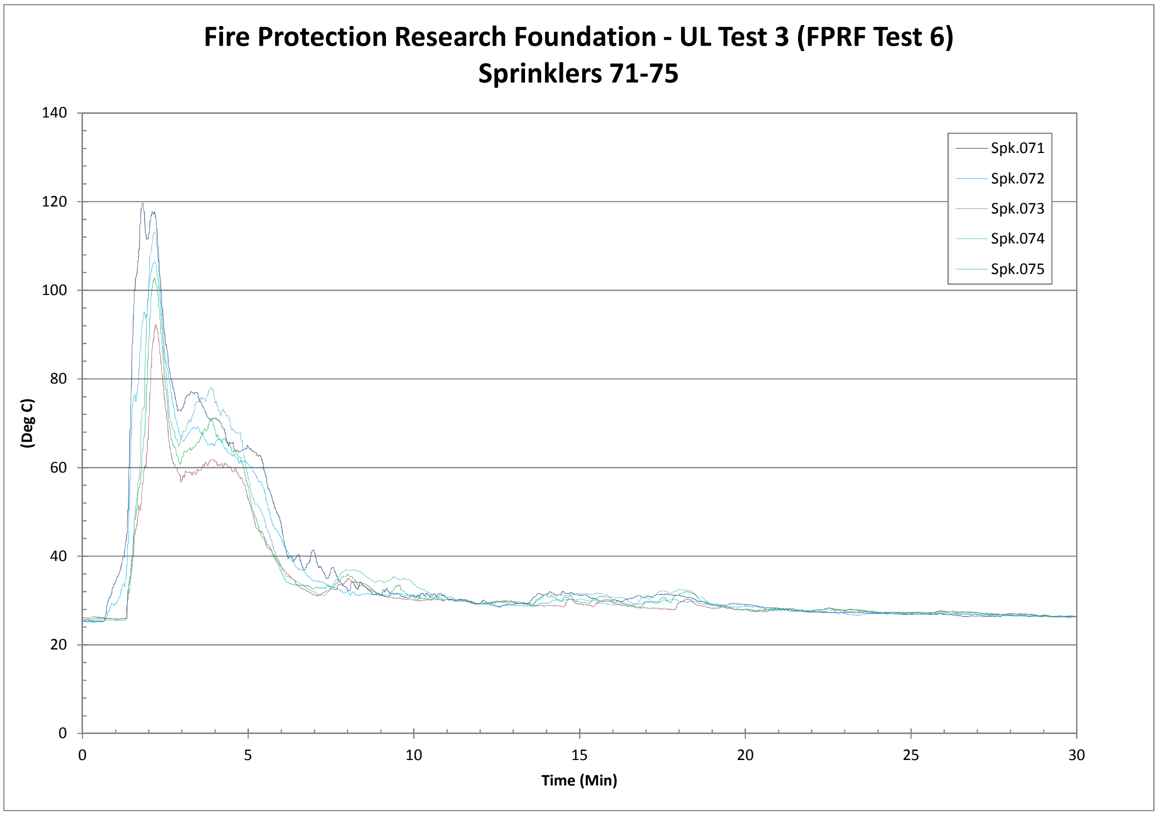

Fire Protection Research Foundation - UL Test 3 (FPRF Test 6)
Sprinklers 46-50
(Deg C)
Time (Min)
Spk.046
Spk.047
Spk.048
Spk.049
Spk.050
0
20
40
60
80
100
120
140
160
180
0
5
10
15
20
25
30

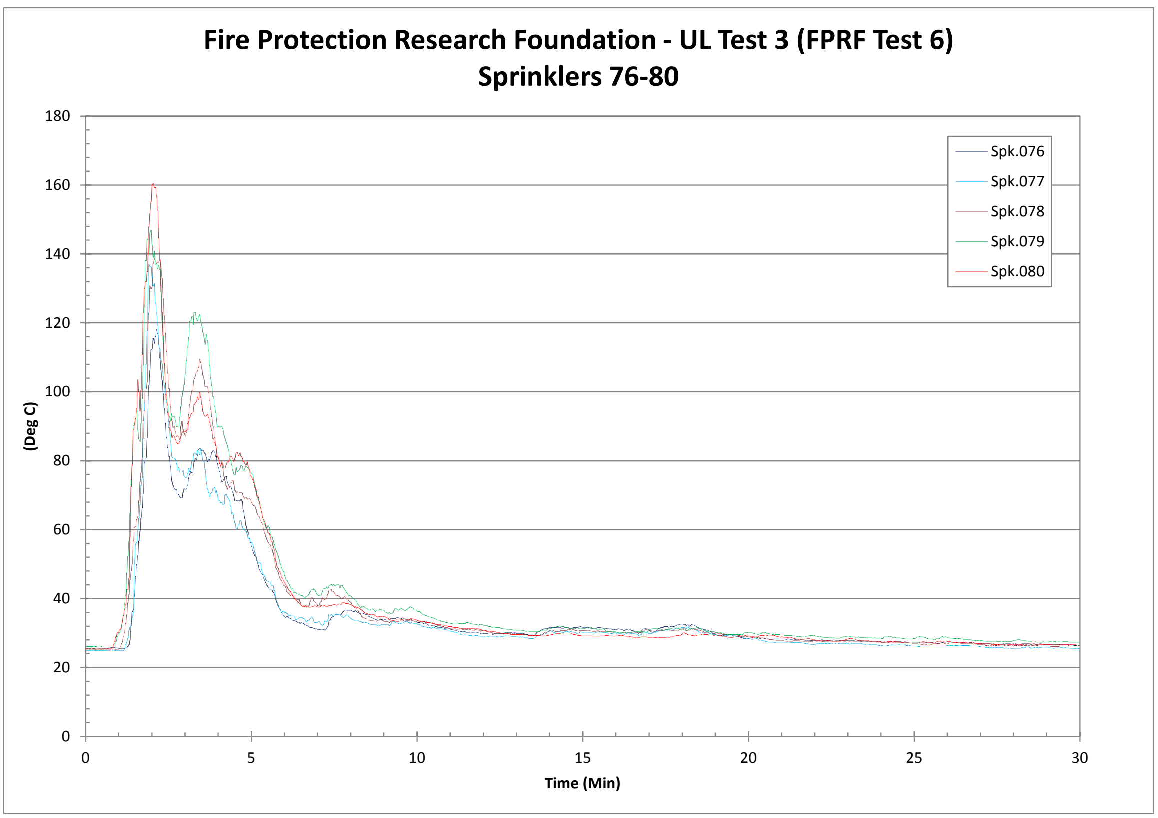

Fire Protection Research Foundation - UL Test 3 (FPRF Test 6)
Sprinklers 51-55
(Deg C)
Time (Min)
Spk.051
Spk.052
Spk.053
Spk.054
Spk.055
0
50
100
150
200
250
300
350
400
450
0
5
10
15
20
25
30

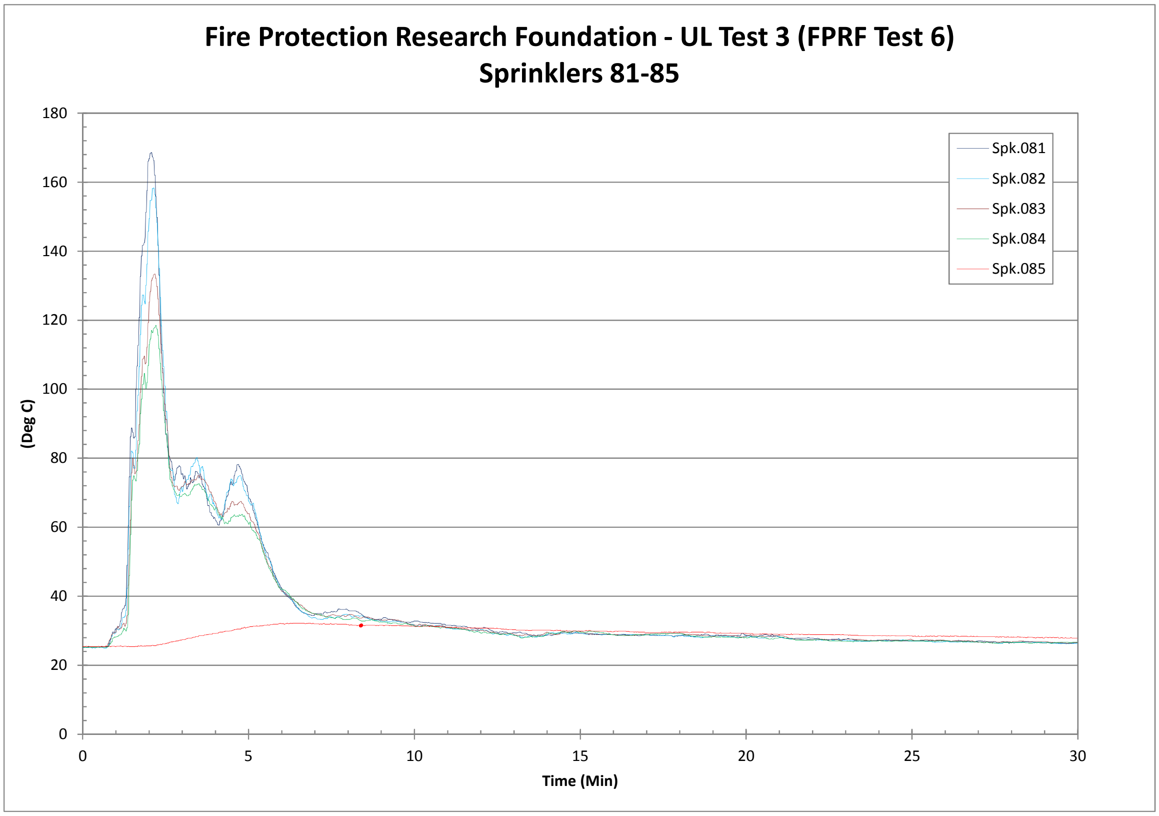

Fire Protection Research Foundation - UL Test 3 (FPRF Test 6)
Sprinklers 56-60
(Deg C)
Time (Min)
Spk.056
Spk.057
Spk.058
Spk.059
Spk.060
0
50
100
150
200
250
300
350
0
5
10
15
20
25
30

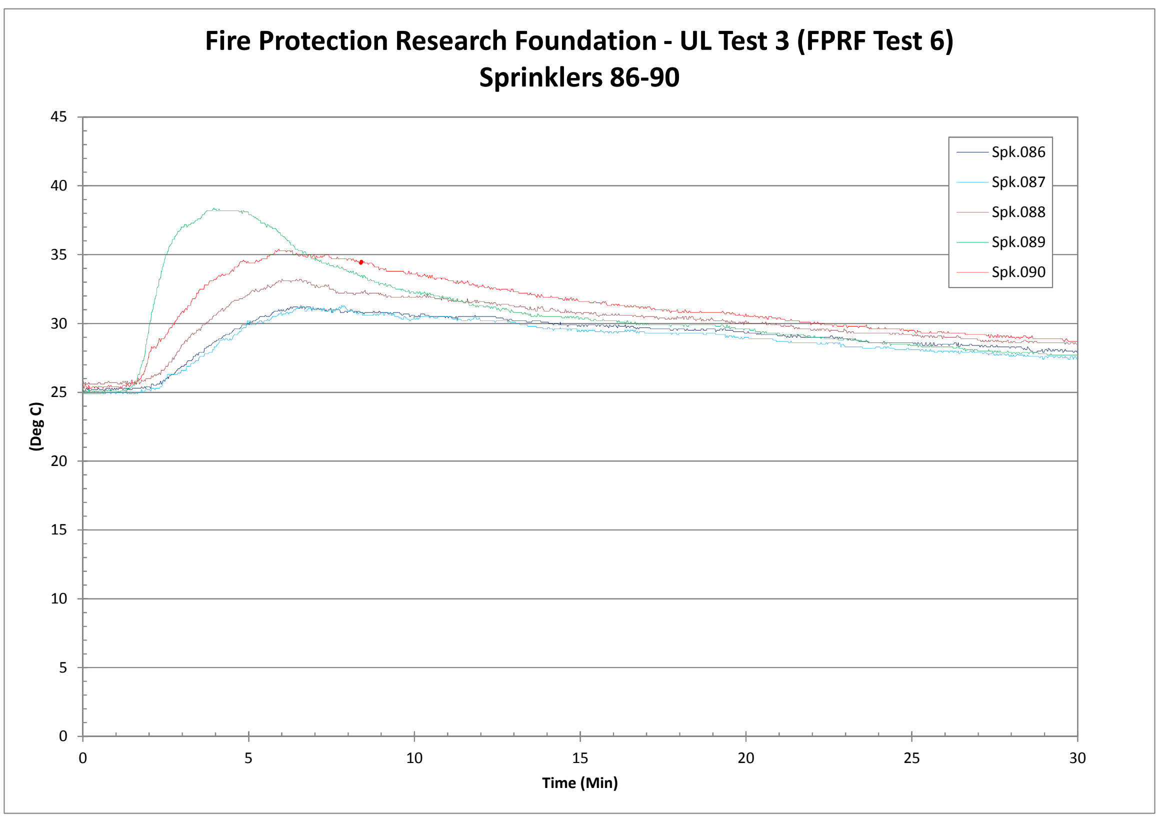

Fire Protection Research Foundation - UL Test 3 (FPRF Test 6)
Sprinklers 61-65
(Deg C)
300
250
200
150
100
50
0
0
5
10
15
20
25
30
Time (Min)
Spk.061
Spk.062
Spk.063
Spk.064
Spk.065

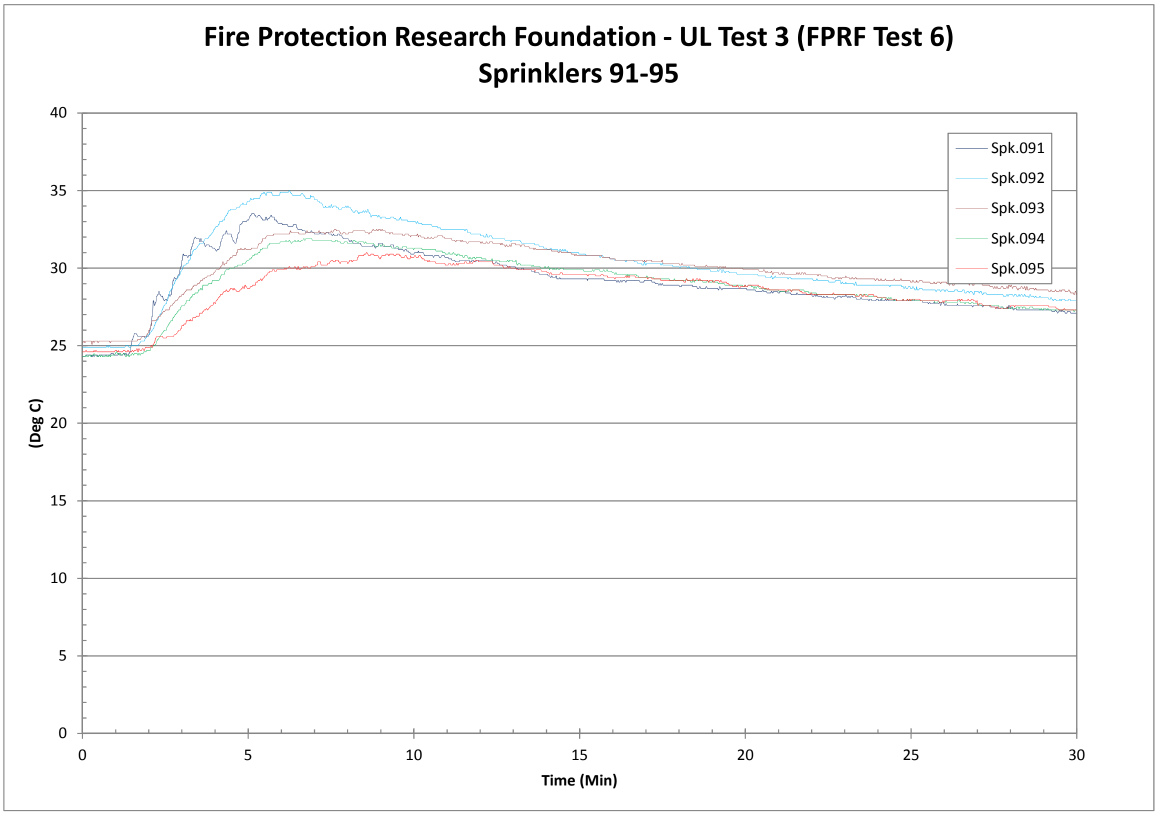

Fire Protection Research Foundation - UL Test 3 (FPRF Test 6)
Sprinklers 66-70
(Deg C)
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
Time (Min)
Spk.066
Spk.067
Spk.068
Spk.069
Spk.070

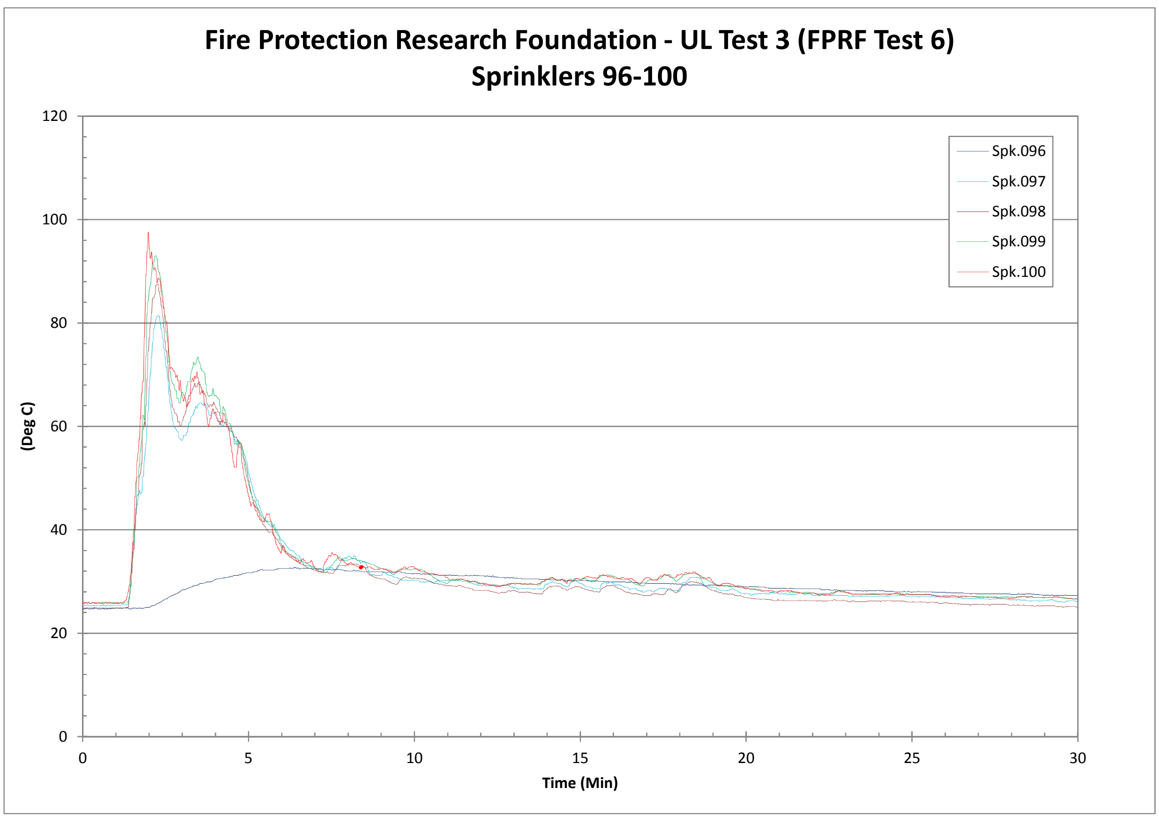

Fire Protection Research Foundation - UL Test 3 (FPRF Test 6)
Sprinklers 71-75
(Deg C)
140
120
100
80
60
40
20
0
0
5
10
15
20
25
30
Time (Min)
Spk.071
Spk.072
Spk.073
Spk.074
Spk.075

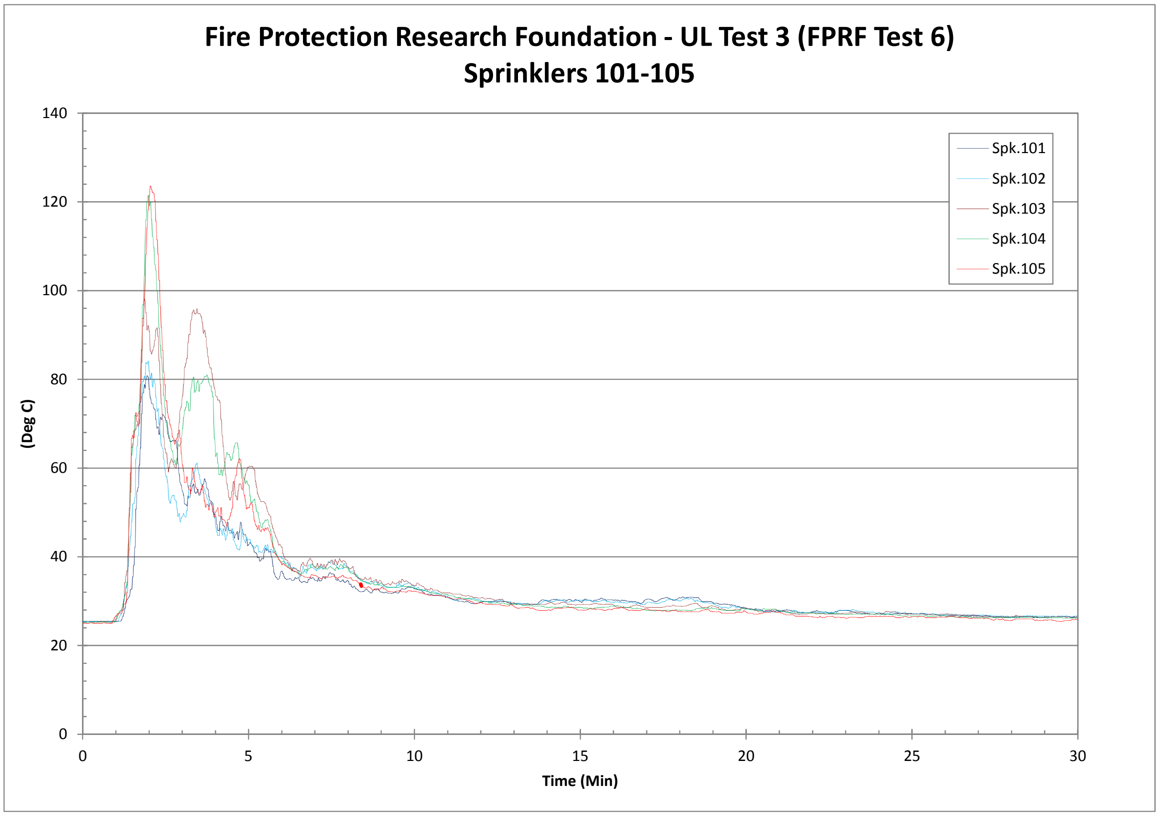

Fire Protection Research Foundation - UL Test 3 (FPRF Test 6)
Sprinklers 76-80
(Deg C)
180
160
140
120
100
80
60
40
20
0
0
5
10
15
20
25
30
Time (Min)
Spk.076
Spk.077
Spk.078
Spk.079
Spk.080

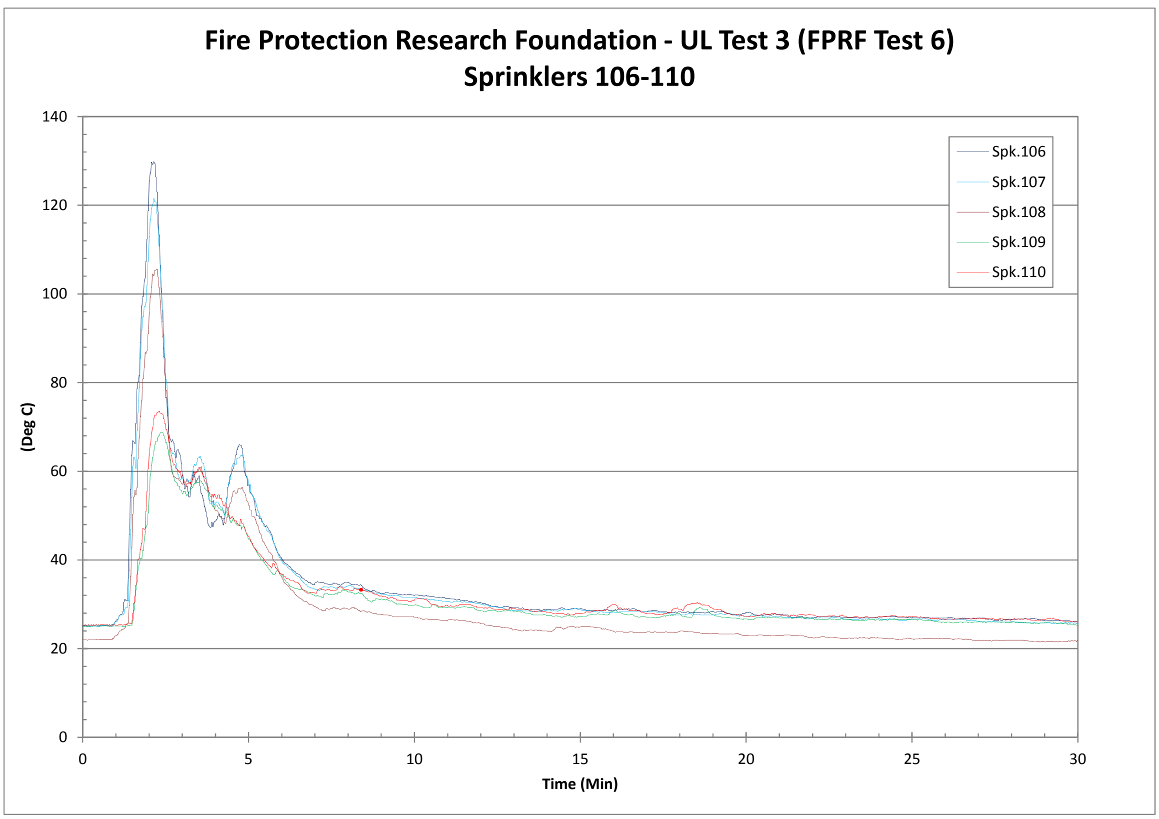

Fire Protection Research Foundation - UL Test 3 (FPRF Test 6)
Sprinklers 81-85
(Deg C)
Time (Min)
Spk.081
Spk.082
Spk.083
Spk.084
Spk.085
0
20
40
60
80
100
120
140
160
180
0
5
10
15
20
25
30

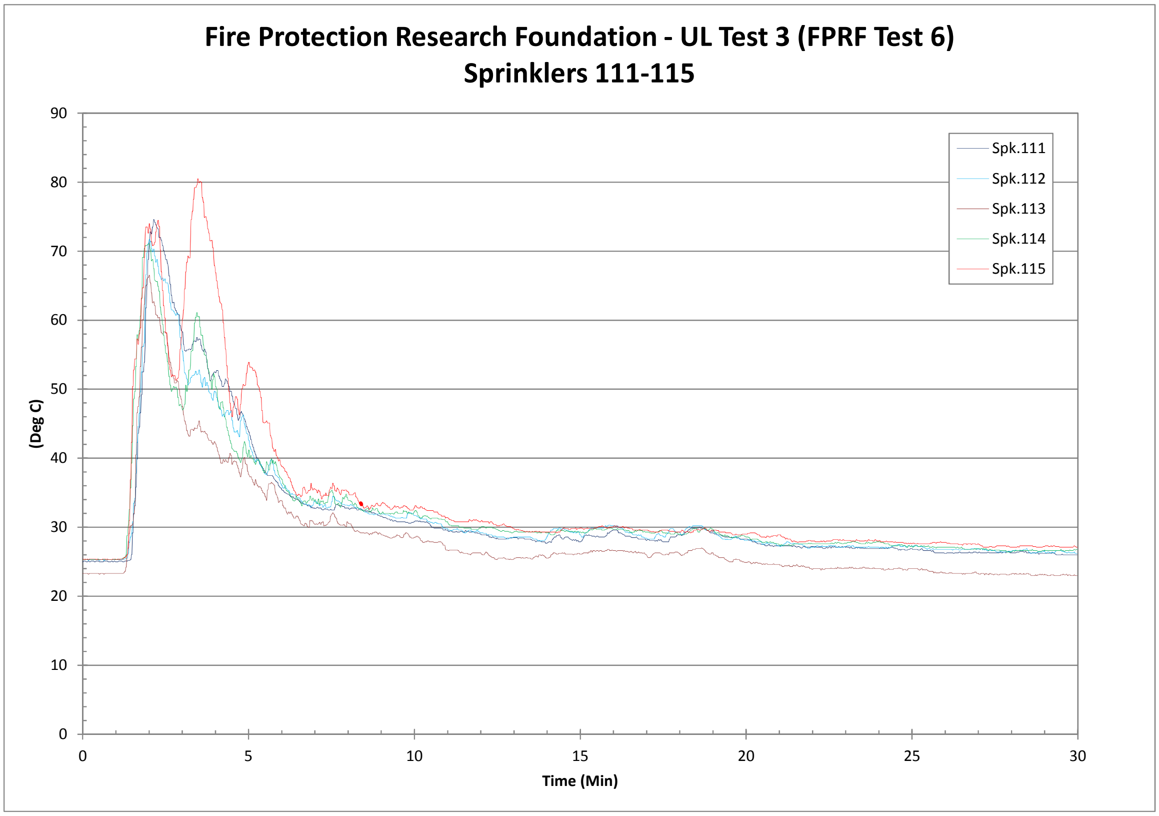

Fire Protection Research Foundation - UL Test 3 (FPRF Test 6)
Sprinklers 86-90
(Deg C)
Time (Min)
Spk.086
Spk.087
Spk.088
Spk.089
Spk.090
0
5
10
15
20
25
30
35
40
45
0
5
10
15
20
25
30

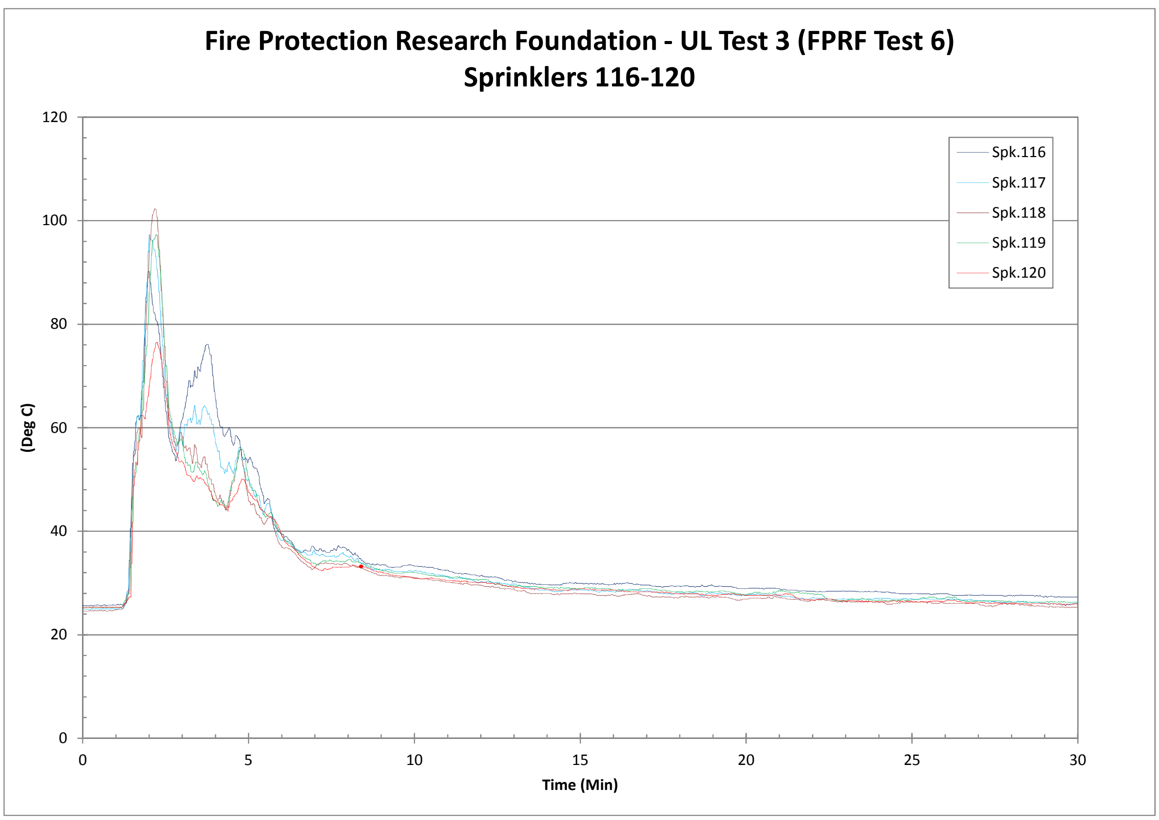

Fire Protection Research Foundation - UL Test 3 (FPRF Test 6)
Sprinklers 91-95
(Deg C)
Time (Min)
Spk.091
Spk.092
Spk.093
Spk.094
Spk.095

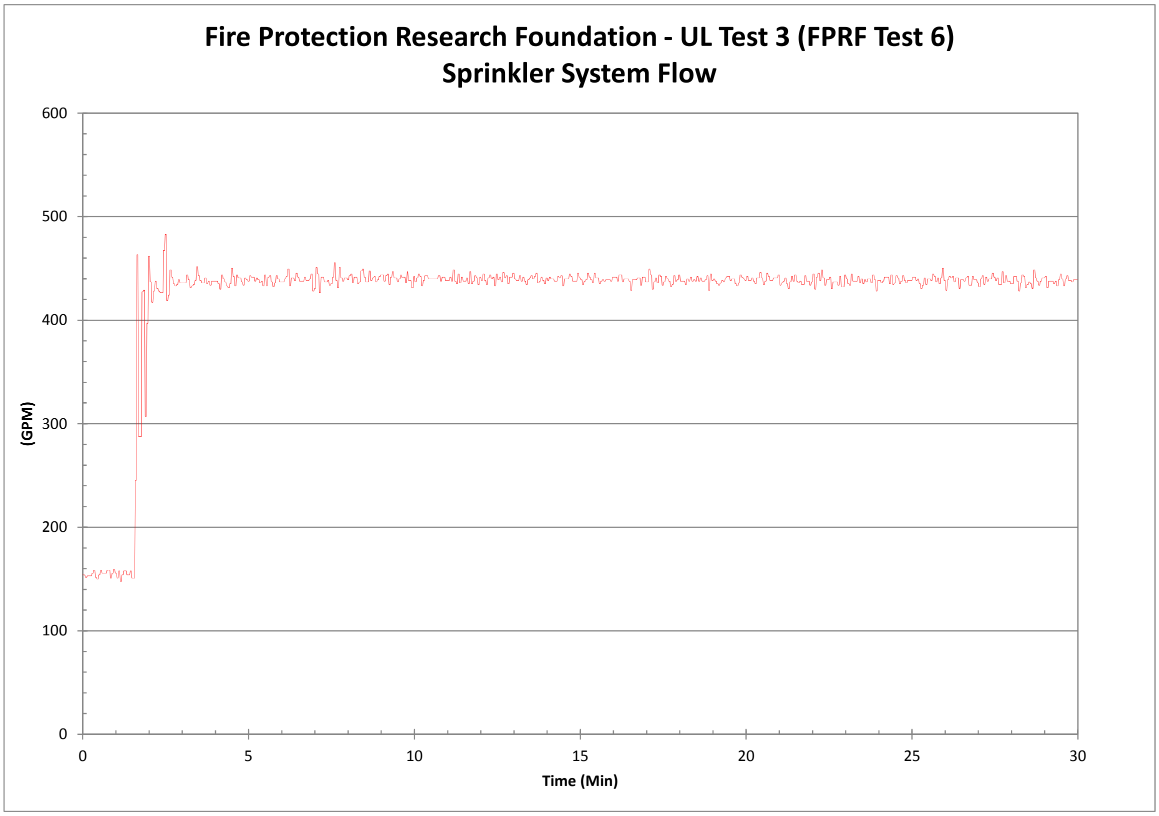

Fire Protection Research Foundation - UL Test 3 (FPRF Test 6)
Sprinklers 96-100
(Deg C)
Time (Min)
Spk.096
Spk.097
Spk.098
Spk.099
Spk.100

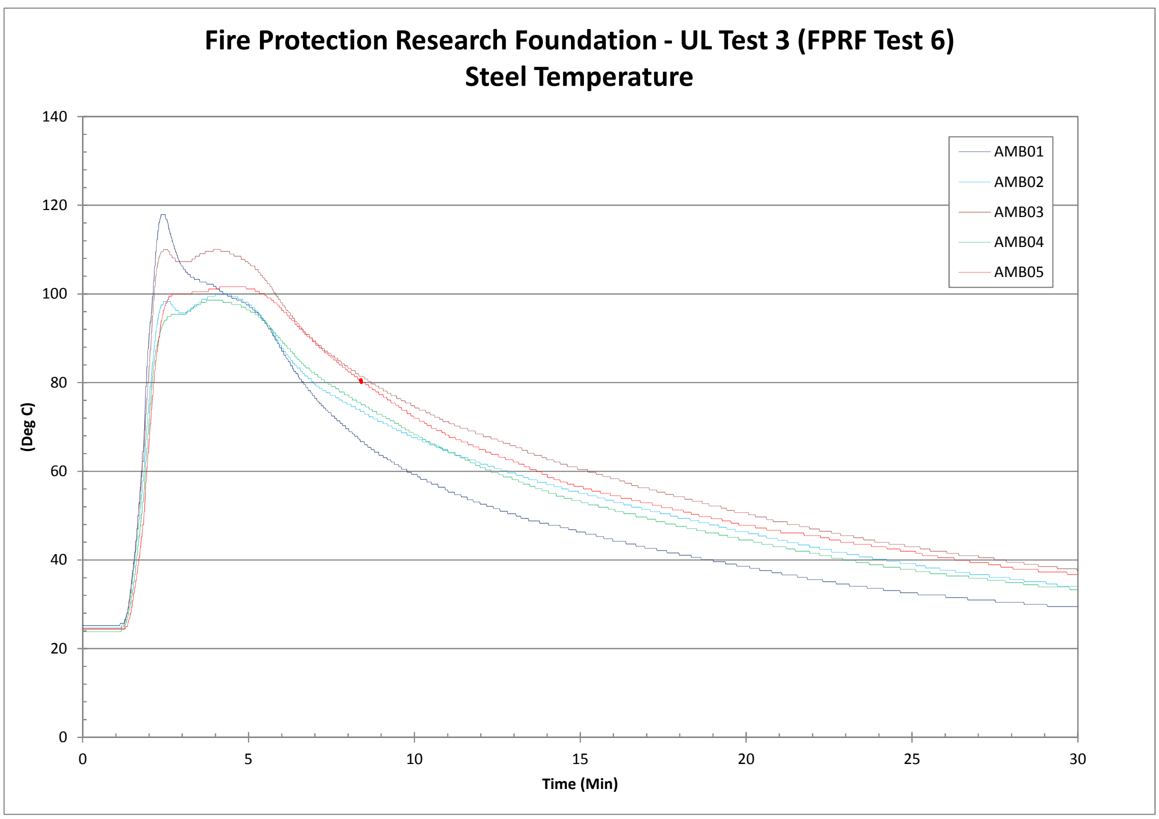

Fire Protection Research Foundation - UL Test 3 (FPRF Test 6)
Sprinklers 101-105
(Deg C)
Time (Min)
Spk.101
Spk.102
Spk.103
Spk.104
Spk.105
0
20
40
60
80
100
120
140
0
5
10
15
20
25
30

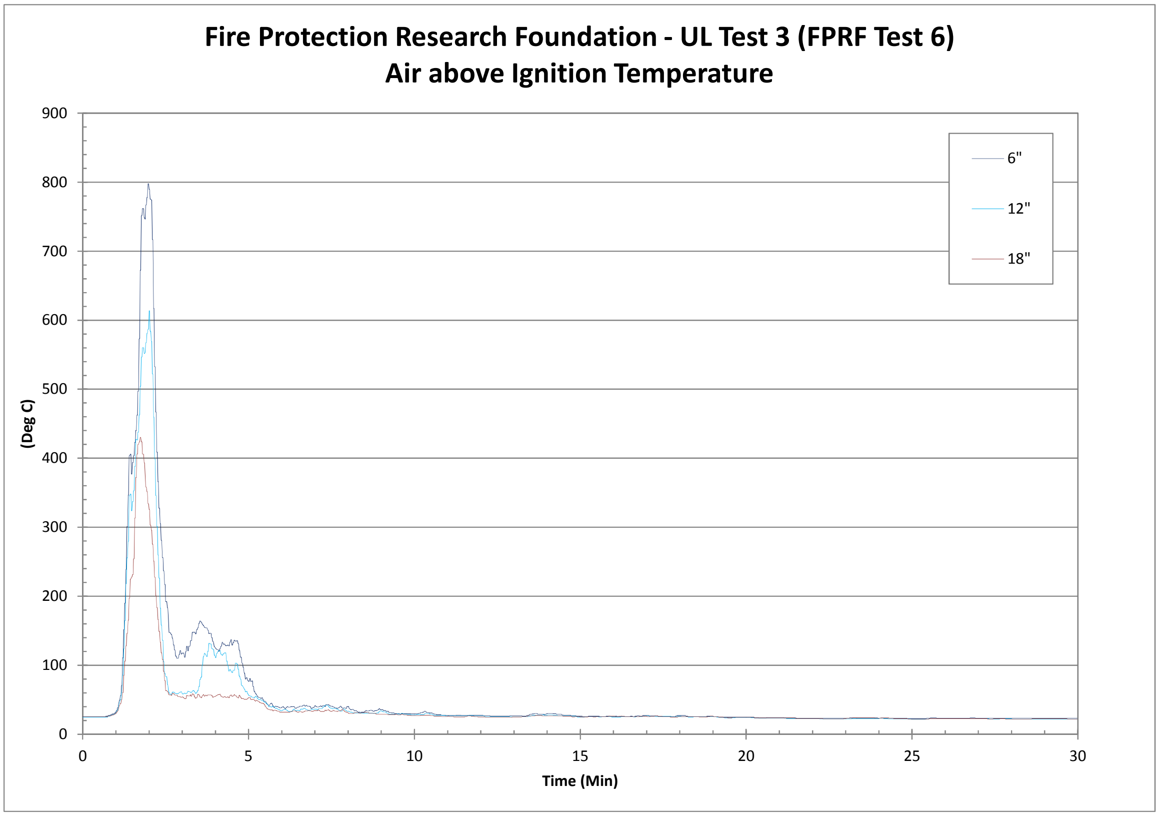

Fire Protection Research Foundation - UL Test 3 (FPRF Test 6)
Sprinklers 106-110
(Deg C)
Time (Min)
Spk.106
Spk.107
Spk.108
Spk.109
Spk.110
0
20
40
60
80
100
120
140
0
5
10
15
20
25
30

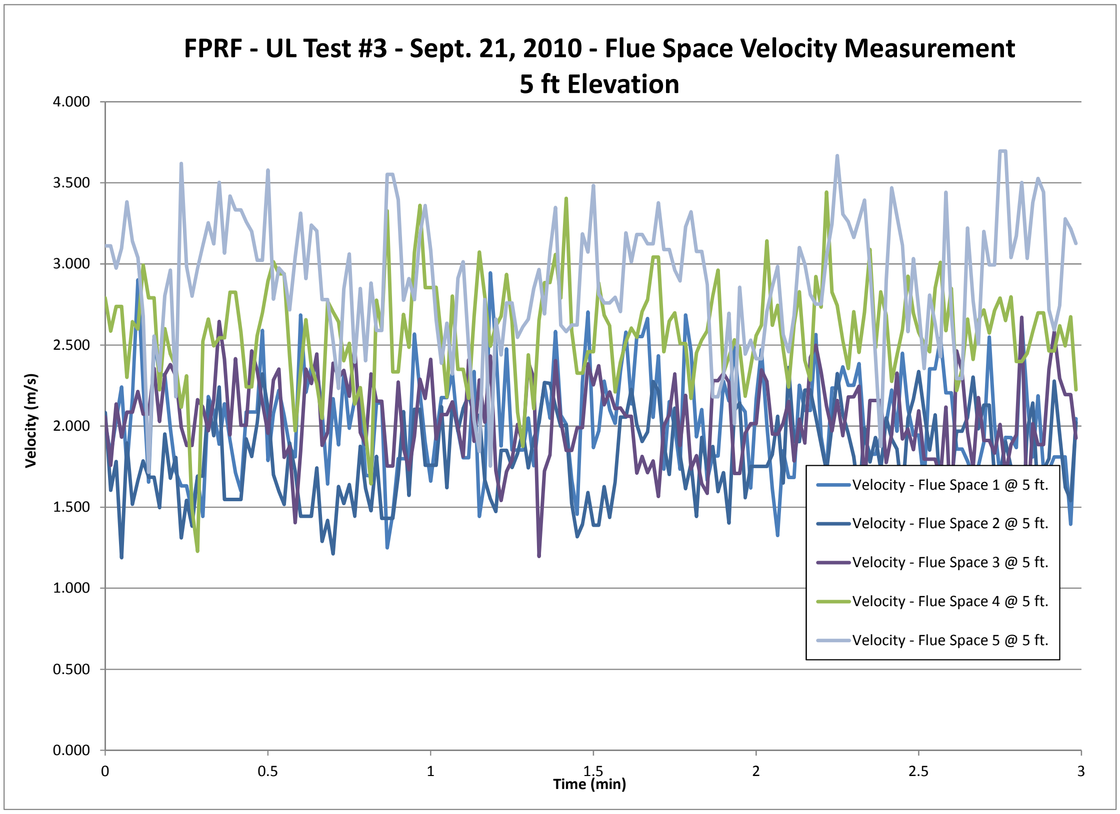

Fire Protection Research Foundation - UL Test 3 (FPRF Test 6)
Sprinklers 111-115
(Deg C)
Time (Min)
Spk.111
Spk.112
Spk.113
Spk.114
Spk.115
0
10
20
30
40
50
60
70
80
90
0
5
10
15
20
25
30

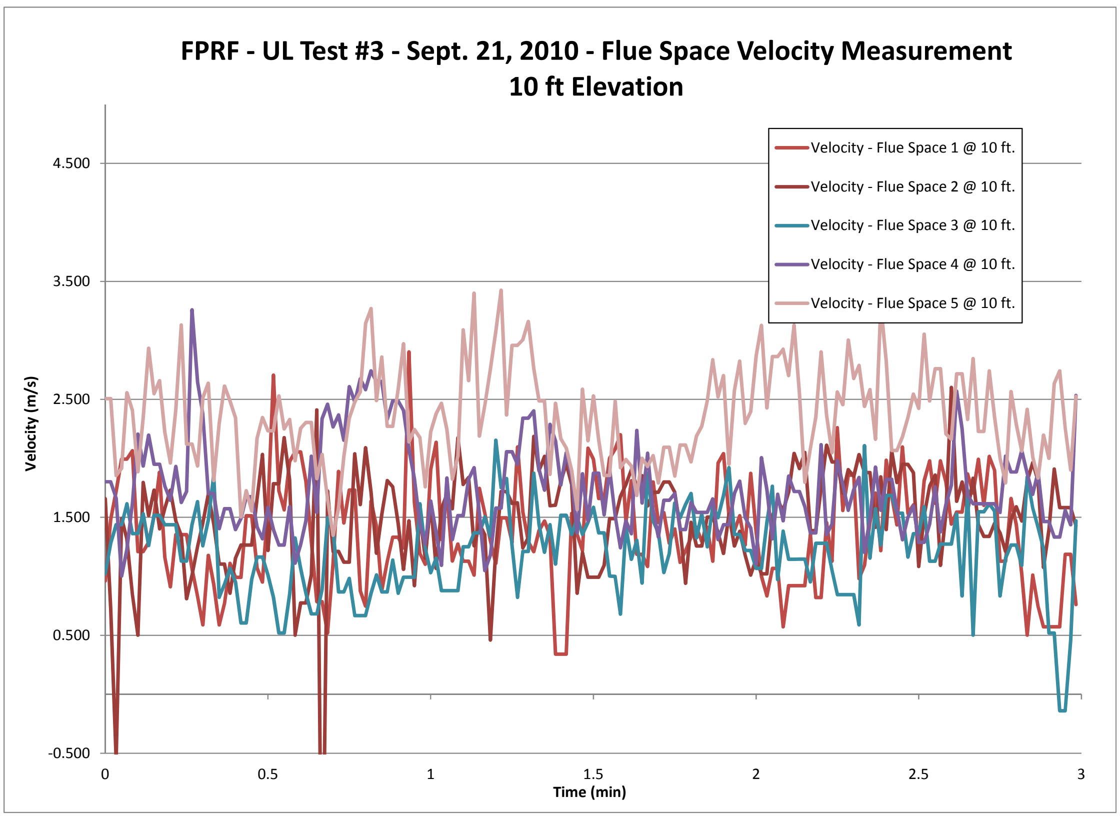

Fire Protection Research Foundation - UL Test 3 (FPRF Test 6)
Sprinklers 116-120
(Deg C)
Time (Min)
Spk.116
Spk.117
Spk.118
Spk.119
Spk.120
0
20
40
60
80
100
120
0
5
10
15
20
25
30

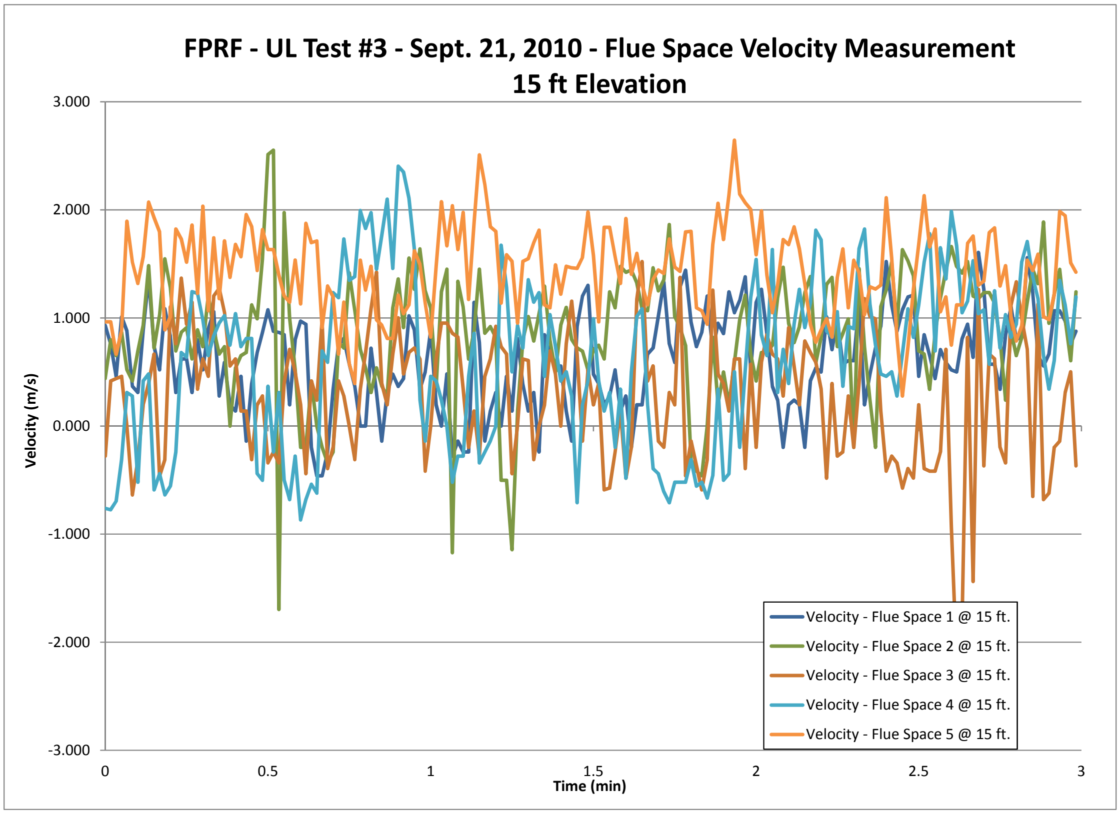

Fire Protection Research Foundation - UL Test 3 (FPRF Test 6)
Sprinkler System Flow
(GPM)
0
100
200
300
400
500
600
0
5
10
15
20
25
30
Time (Min)

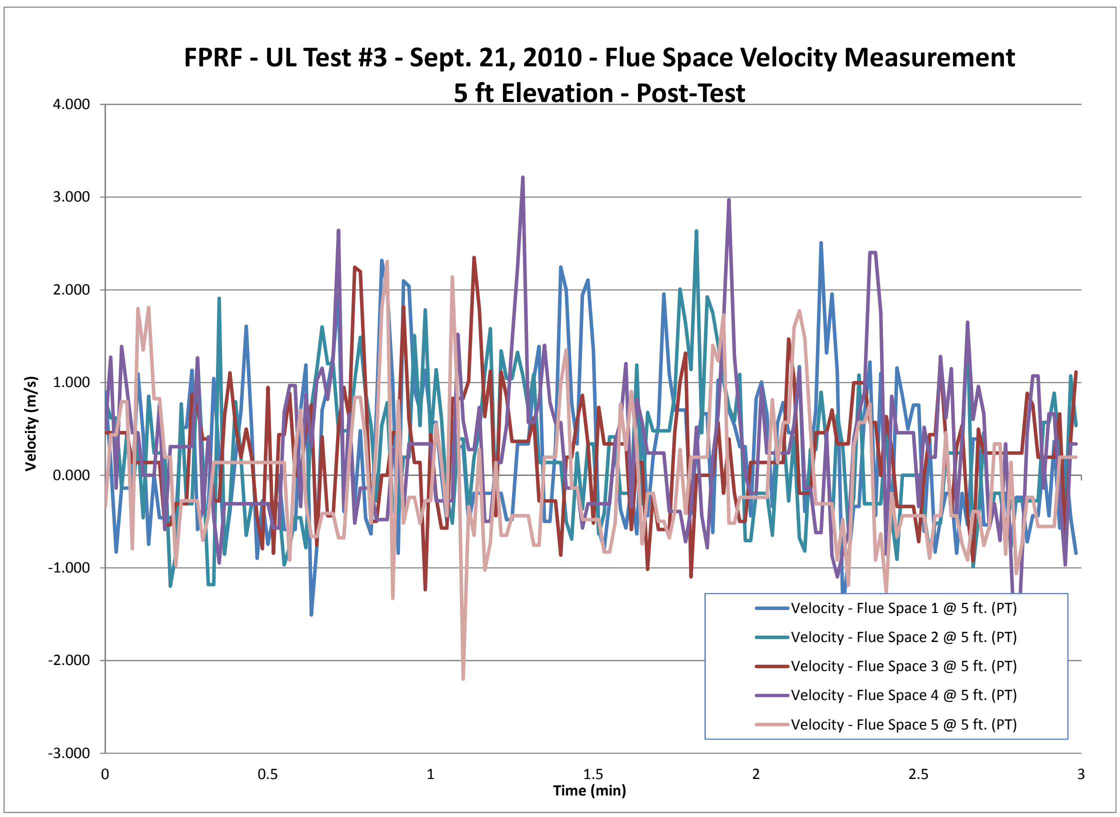

Fire Protection Research Foundation - UL Test 3 (FPRF Test 6)
Steel Temperature
(Deg C)
0
20
40
60
80
100
120
140
0
5
10
15
20
25
30
Time (Min)
AMB01
AMB02
AMB03
AMB04
AMB05

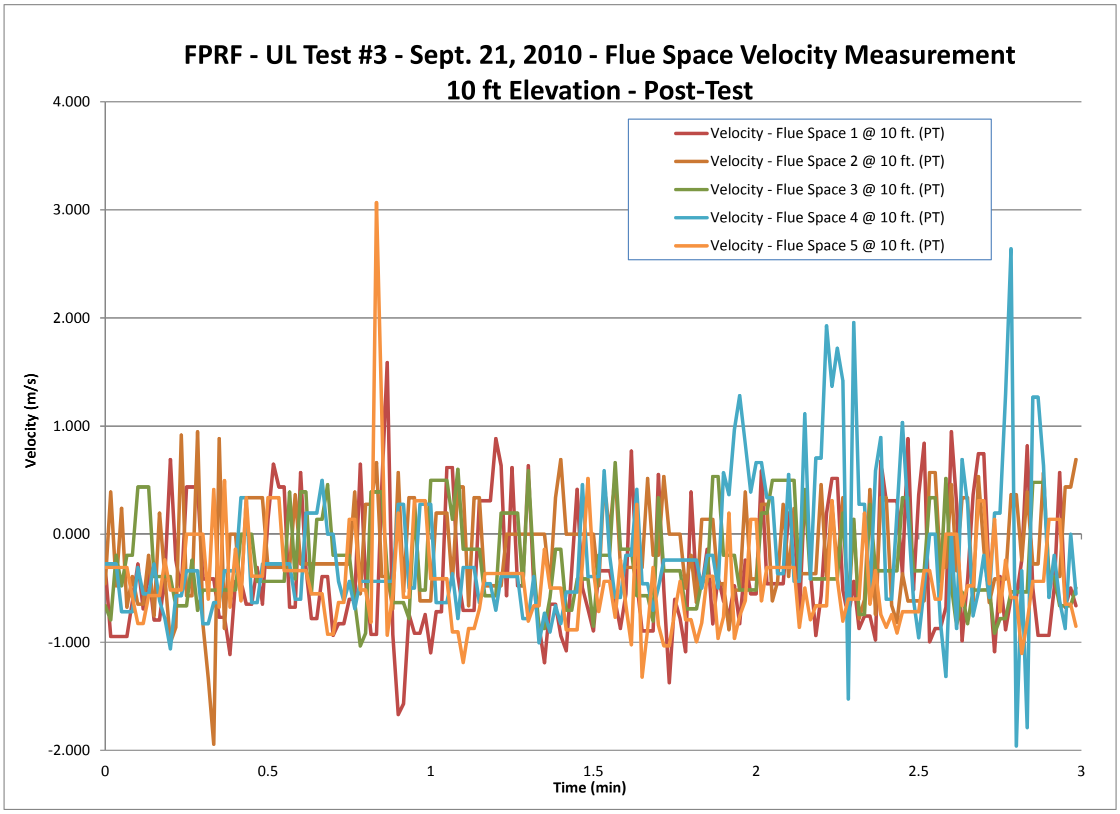

Fire Protection Research Foundation - UL Test 3 (FPRF Test 6)
Air above Ignition Temperature
(Deg C)
900
800
700
600
500
400
300
200
100
0
0
5
10
15
20
25
30
Time (Min)
6"
12"
18"

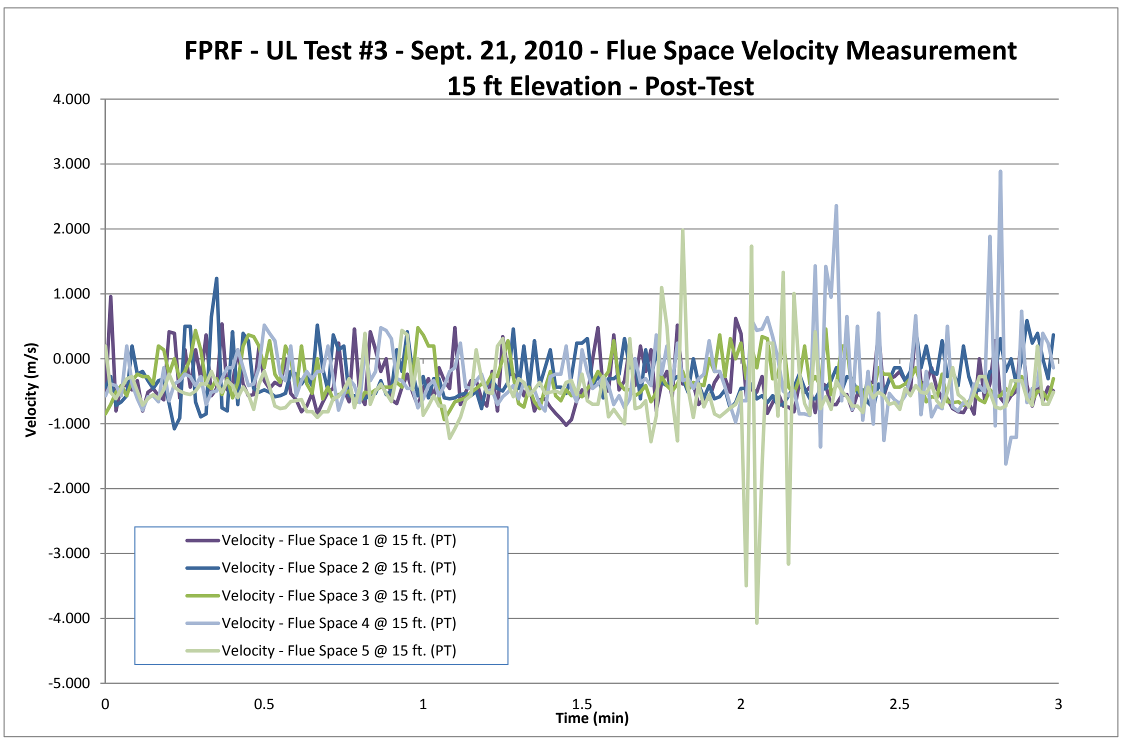

FPRF - UL Test #3 - Sept. 21, 2010 - Flue Space Velocity Measurement
5 ft Elevation
Velocity (m/s)
4.000
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
0
0.5
1
1.5
2
2.5
3
Time (min)
Velocity - Flue Space 1 @ 5 ft.
Velocity - Flue Space 2 @ 5 ft.
Velocity - Flue Space 3 @ 5 ft.
Velocity - Flue Space 4 @ 5 ft.
Velocity - Flue Space 5 @ 5 ft.


FPRF - UL Test #3 - Sept. 21, 2010 - Flue Space Velocity Measurement
10 ft Elevation
Velocity (m/s)
4.500
3.500
2.500
1.500
0.500
-0.500
0
0.5
1
1.5
2
2.5
3
Time (min)
Velocity - Flue Space 1 @ 10 ft.
Velocity - Flue Space 2 @ 10 ft.
Velocity - Flue Space 3 @ 10 ft.
Velocity - Flue Space 4 @ 10 ft.
Velocity - Flue Space 5 @ 10 ft.

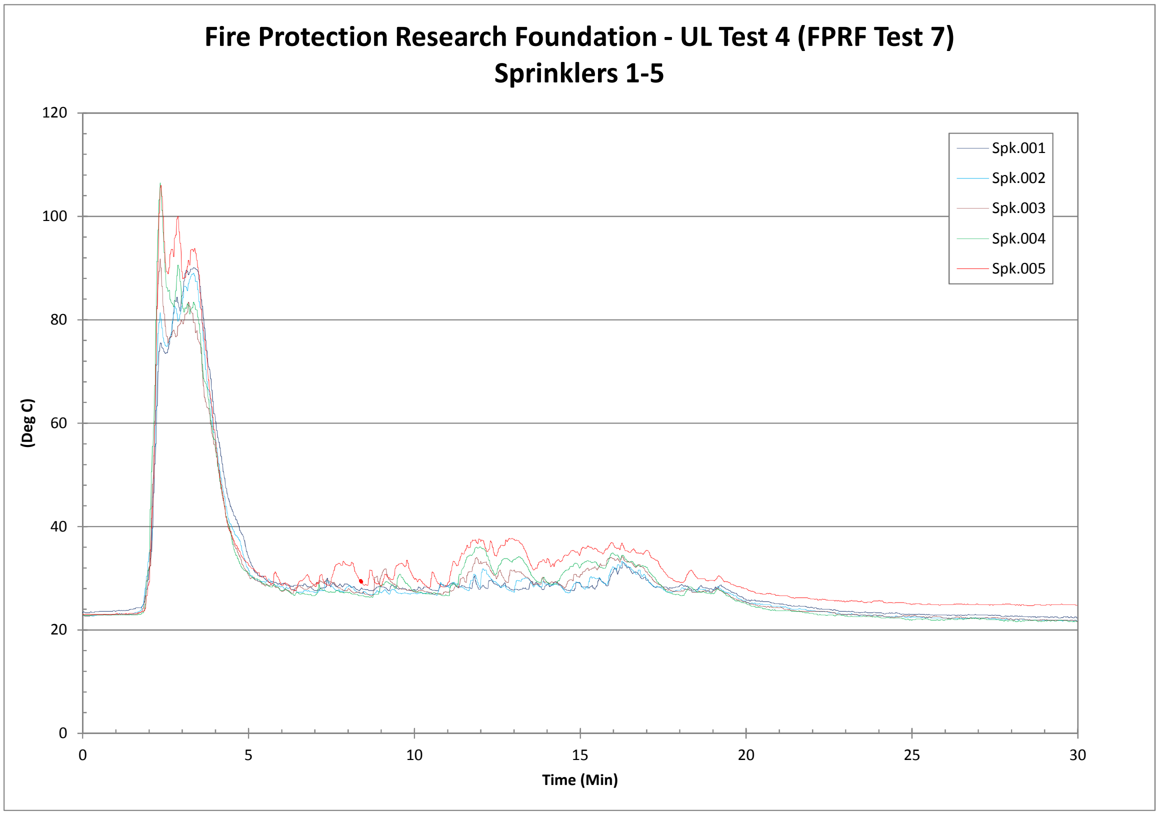

FPRF - UL Test #3 - Sept. 21, 2010 - Flue Space Velocity Measurement
15 ft Elevation
Velocity (m/s)
Time (min)
3.000
2.000
1.000
0.000
-1.000
-2.000
-3.000
0
0.5
1
1.5
2
2.5
3
Velocity - Flue Space 1 @ 15 ft.
Velocity - Flue Space 2 @ 15 ft.
Velocity - Flue Space 3 @ 15 ft.
Velocity - Flue Space 4 @ 15 ft.
Velocity - Flue Space 5 @ 15 ft.

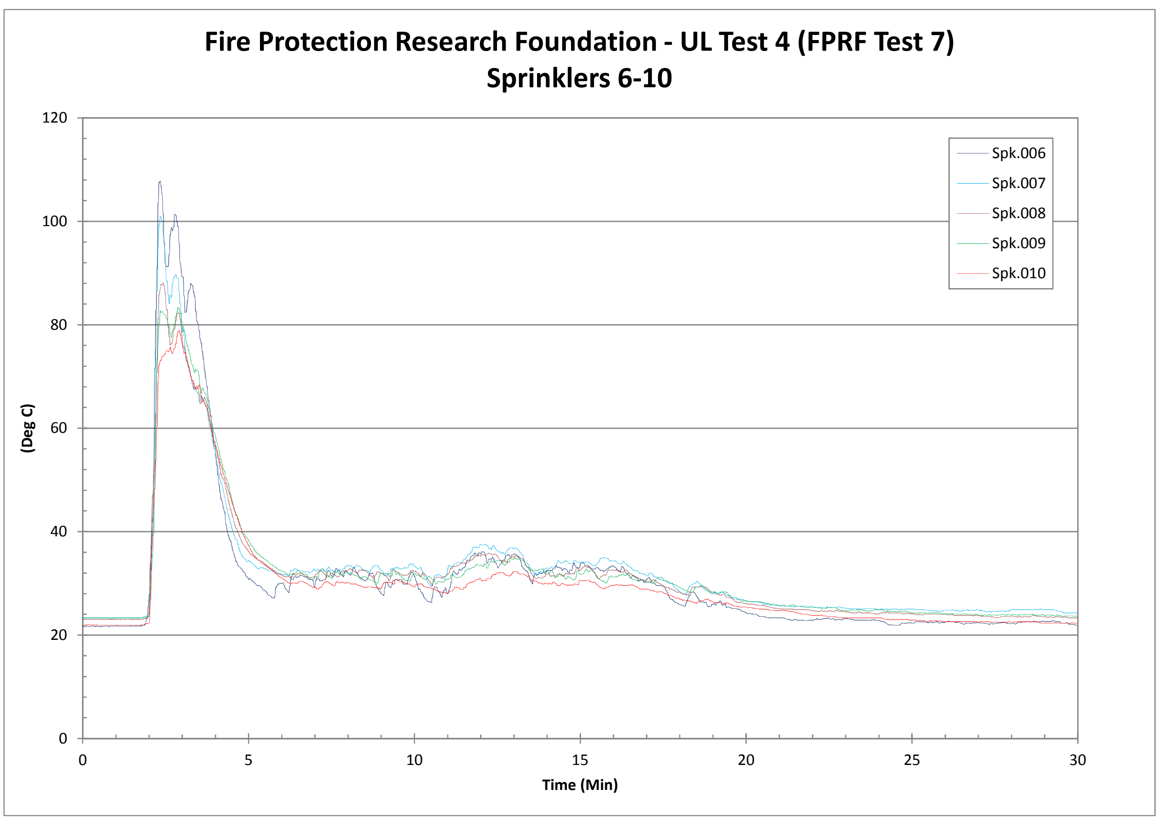

FPRF - UL Test #3 - Sept. 21, 2010 - Flue Space Velocity Measurement
5 ft Elevation - Post-Test
Velocity (m/s)
Time (min)
4.000
3.000
2.000
1.000
0.000
-1.000
-2.000
-3.000
0
0.5
1
1.5
2
2.5
3
Velocity - Flue Space 1 @ 5 ft. (PT)
Velocity - Flue Space 2 @ 5 ft. (PT)
Velocity - Flue Space 3 @ 5 ft. (PT)
Velocity - Flue Space 4 @ 5 ft. (PT)
Velocity - Flue Space 5 @ 5 ft. (PT)

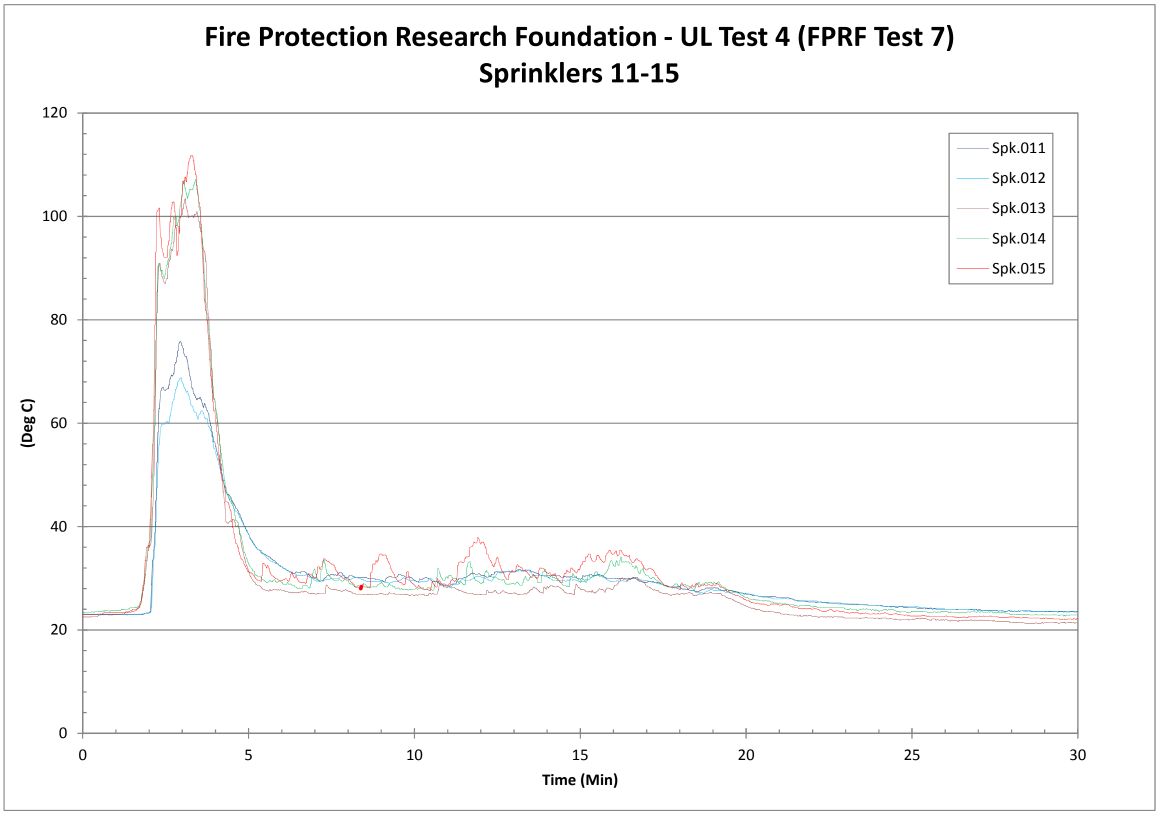

FPRF - UL Test #3 - Sept. 21, 2010 - Flue Space Velocity Measurement
10 ft Elevation - Post-Test
Velocity - Flue Space 1 @ 10 ft. (PT)
Velocity - Flue Space 2 @ 10 ft. (PT)
Velocity - Flue Space 3 @ 10 ft. (PT)
Velocity - Flue Space 4 @ 10 ft. (PT)
Velocity - Flue Space 5 @ 10 ft. (PT)
Velocity (m/s)
4.000
3.000
2.000
1.000
0.000
-1.000
-2.000
0
0.5
1
1.5
2
2.5
3
Time (min)

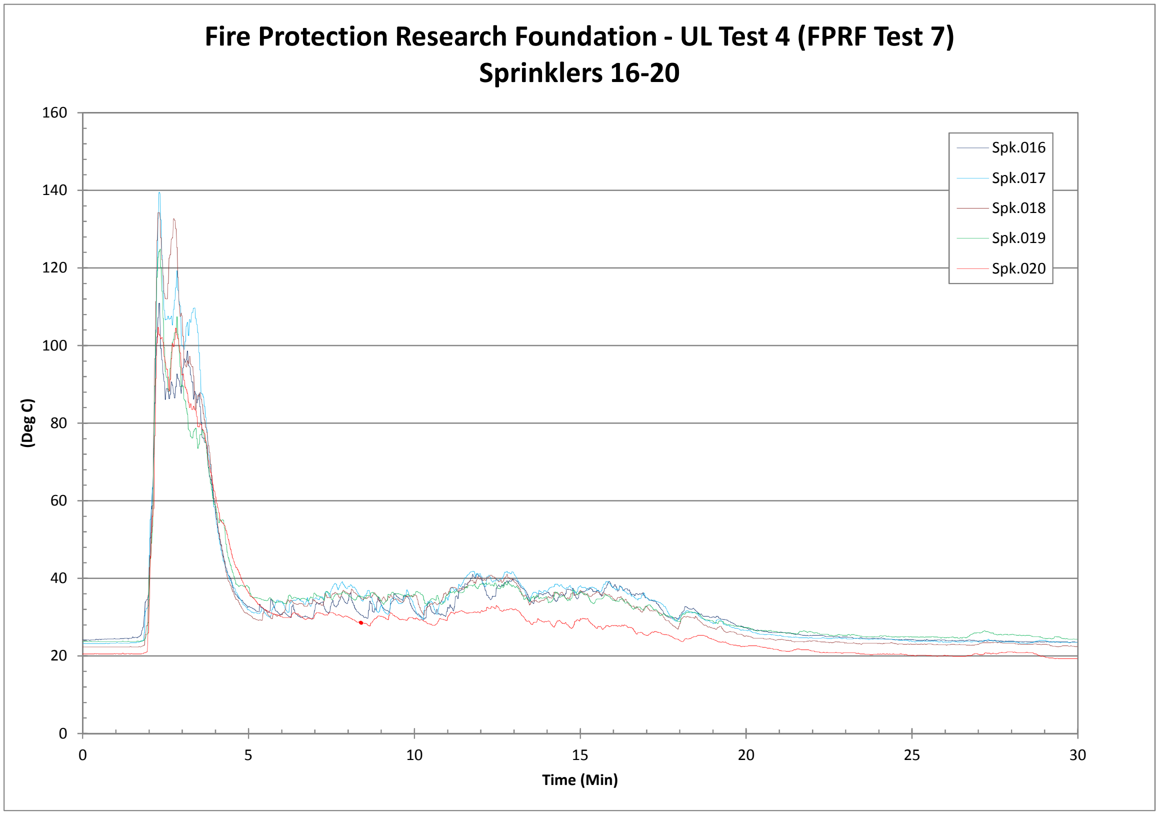

FPRF - UL Test #3 - Sept. 21, 2010 - Flue Space Velocity Measurement
15 ft Elevation - Post-Test
Velocity - Flue Space 1 @ 15 ft. (PT)
Velocity - Flue Space 2 @ 15 ft. (PT)
Velocity - Flue Space 3 @ 15 ft. (PT)
Velocity - Flue Space 4 @ 15 ft. (PT)
Velocity - Flue Space 5 @ 15 ft. (PT)
Velocity (m/s)
4.000
3.000
2.000
1.000
0.000
-1.000
-2.000
-3.000
-4.000
-5.000
0
0.5
1
1.5
2
2.5
3
Time (min)

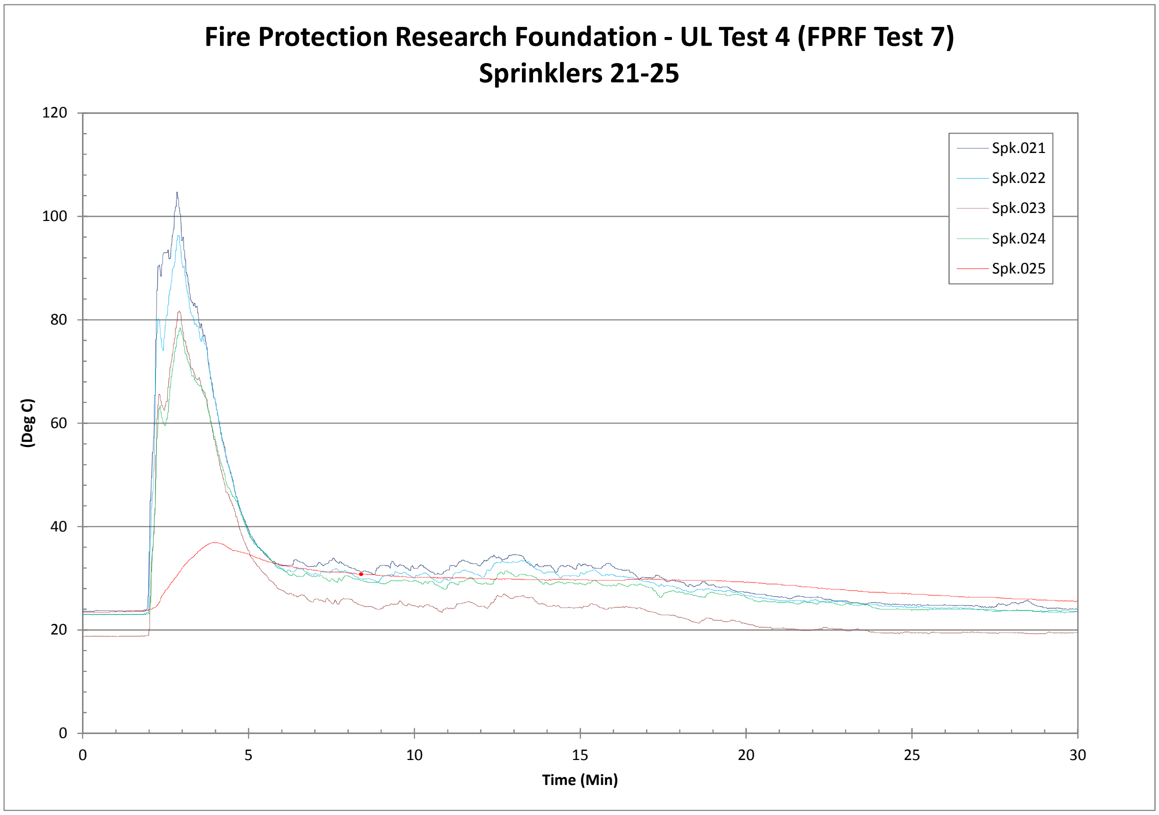
APPENDIX D
Graphical Presentation of
Gas Temperatures, Steel Temperatures, System Waterflow and Velocities - Test 4

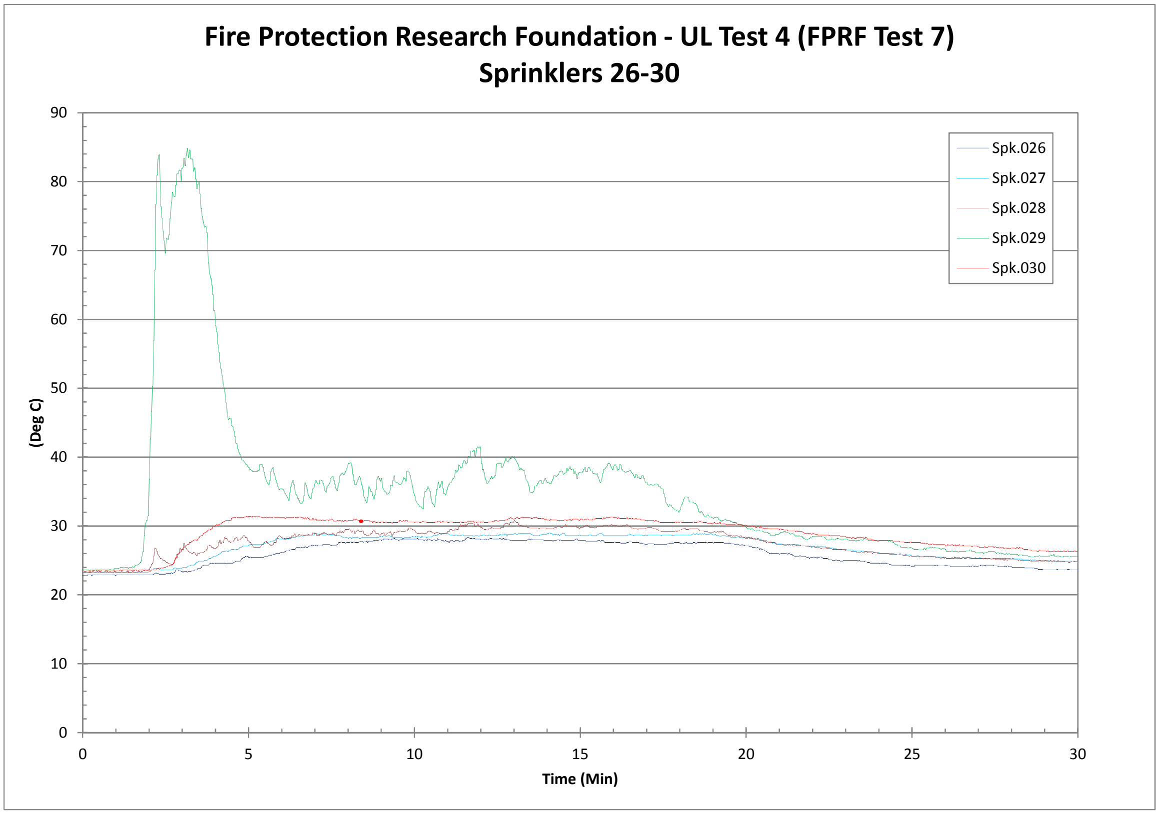

Fire Protection Research Foundation - UL Test 4 (FPRF Test 7)
Sprinklers 1-5
(Deg C)
Time (Min)
Spk.001
Spk.002
Spk.003
Spk.004
Spk.005
0
20
40
60
80
100
120
0
5
10
15
20
25
30

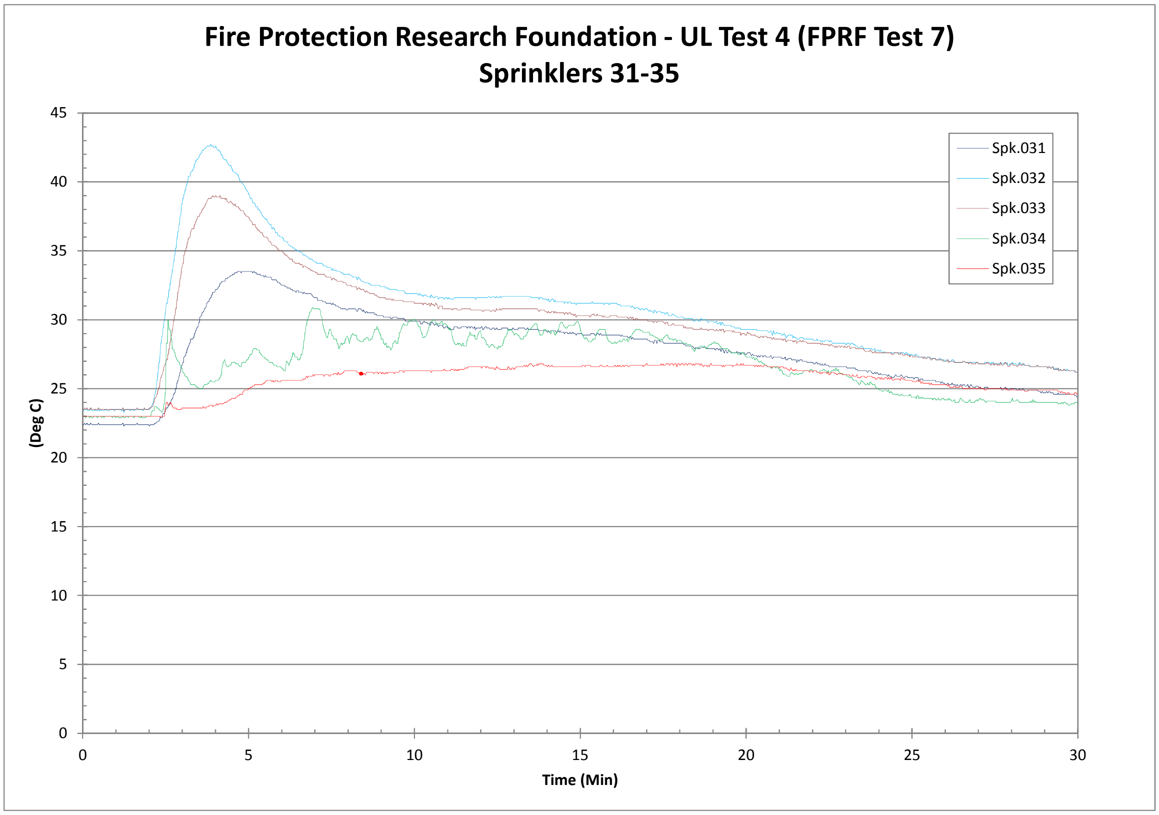

Fire Protection Research Foundation - UL Test 4 (FPRF Test 7)
Sprinklers 6-10
(Deg C)
Time (Min)
Spk.006
Spk.007
Spk.008
Spk.009
Spk.010
0
20
40
60
80
100
120
0
5
10
15
20
25
30

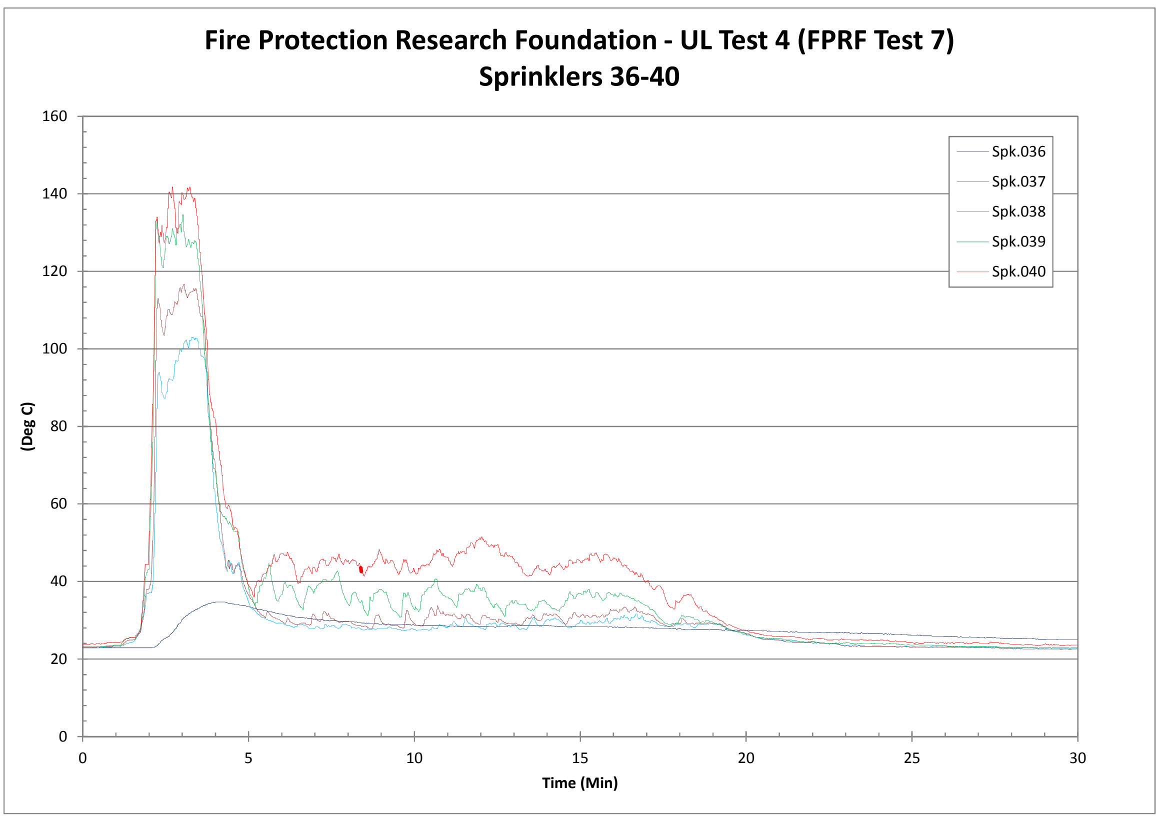

Fire Protection Research Foundation - UL Test 4 (FPRF Test 7)
Sprinklers 11-15
(Deg C)
Time (Min)
Spk.011
Spk.012
Spk.013
Spk.014
Spk.015

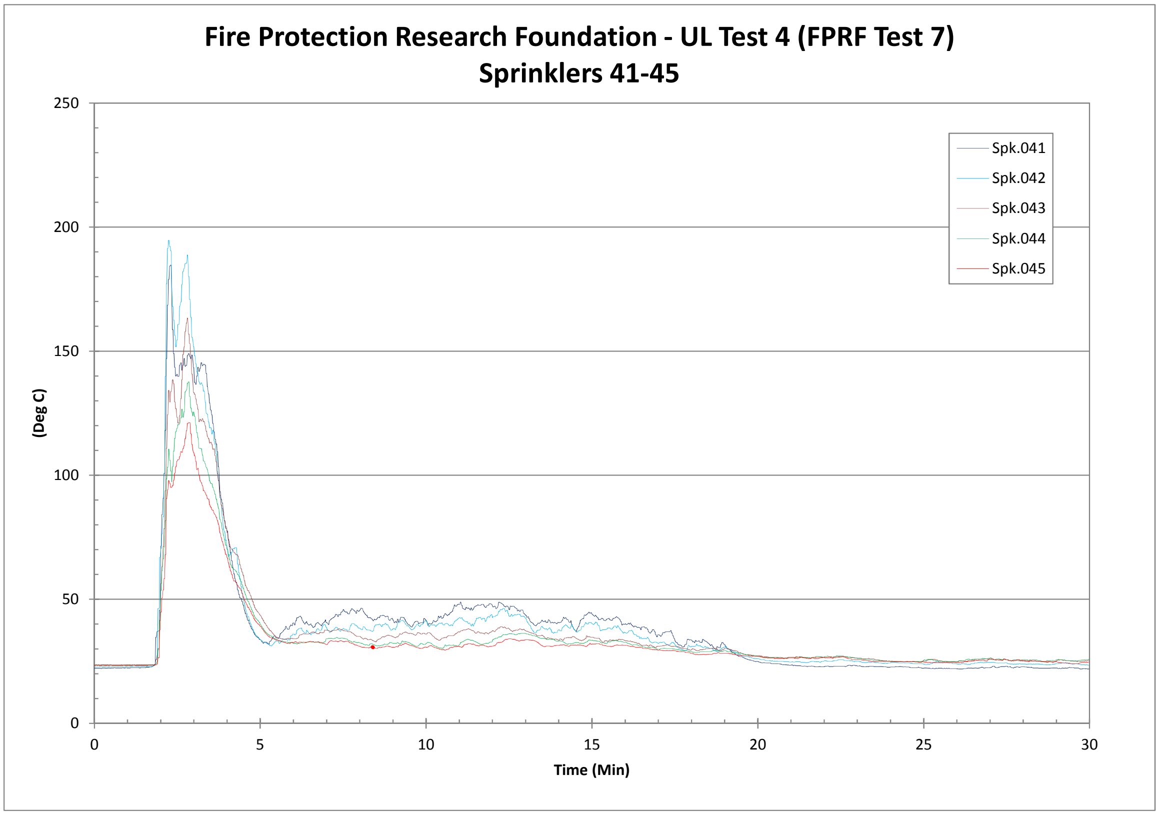

Fire Protection Research Foundation - UL Test 4 (FPRF Test 7)
Sprinklers 16-20
(Deg C)
Time (Min)
Spk.016
Spk.017
Spk.018
Spk.019
Spk.020

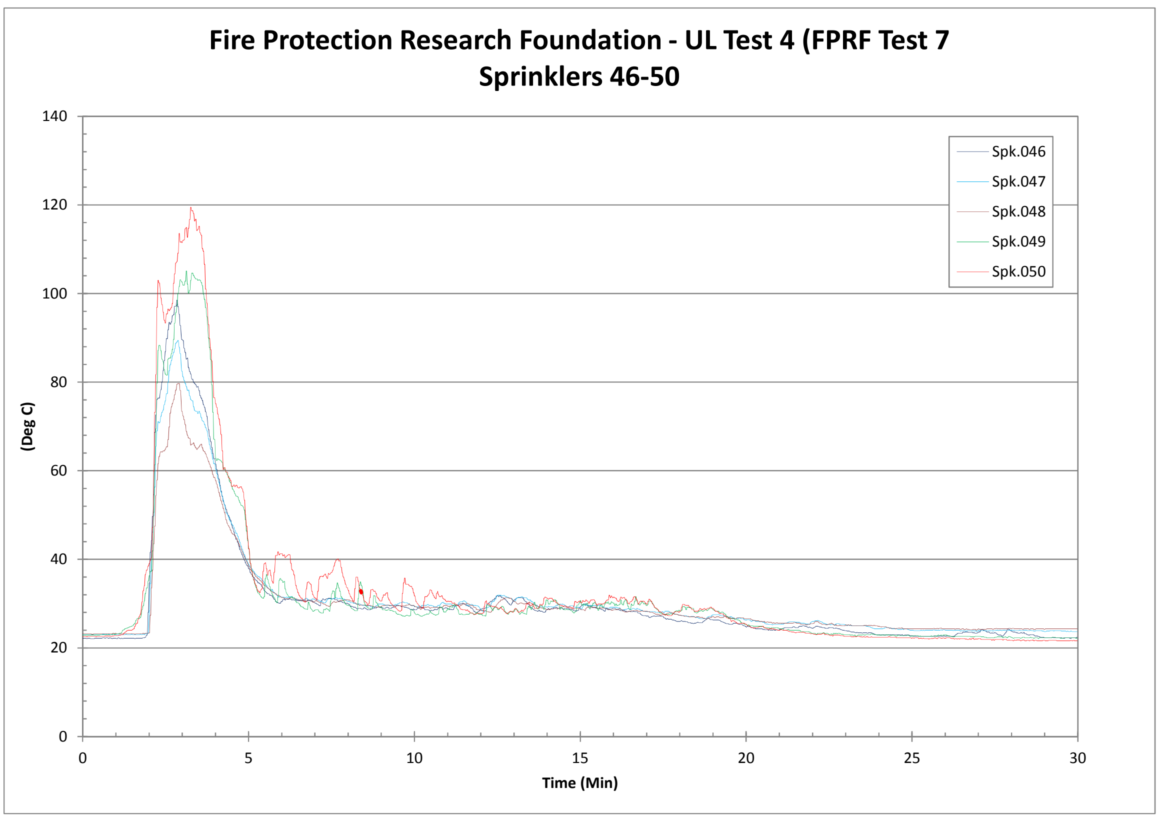

Fire Protection Research Foundation - UL Test 4 (FPRF Test 7)
Sprinklers 21-25
(Deg C)
Time (Min)
Spk.021
Spk.022
Spk.023
Spk.024
Spk.025

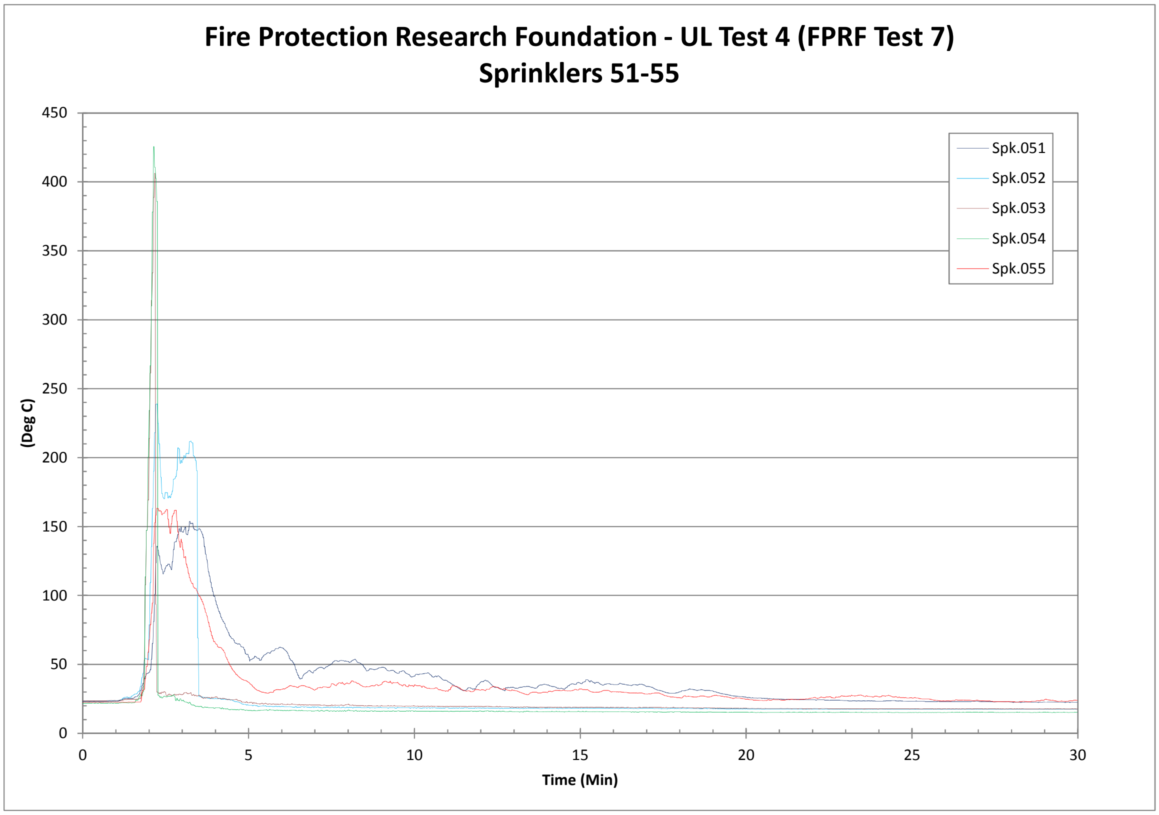

Fire Protection Research Foundation - UL Test 4 (FPRF Test 7)
Sprinklers 26-30
(Deg C)
Time (Min)
Spk.026
Spk.027
Spk.028
Spk.029
Spk.030

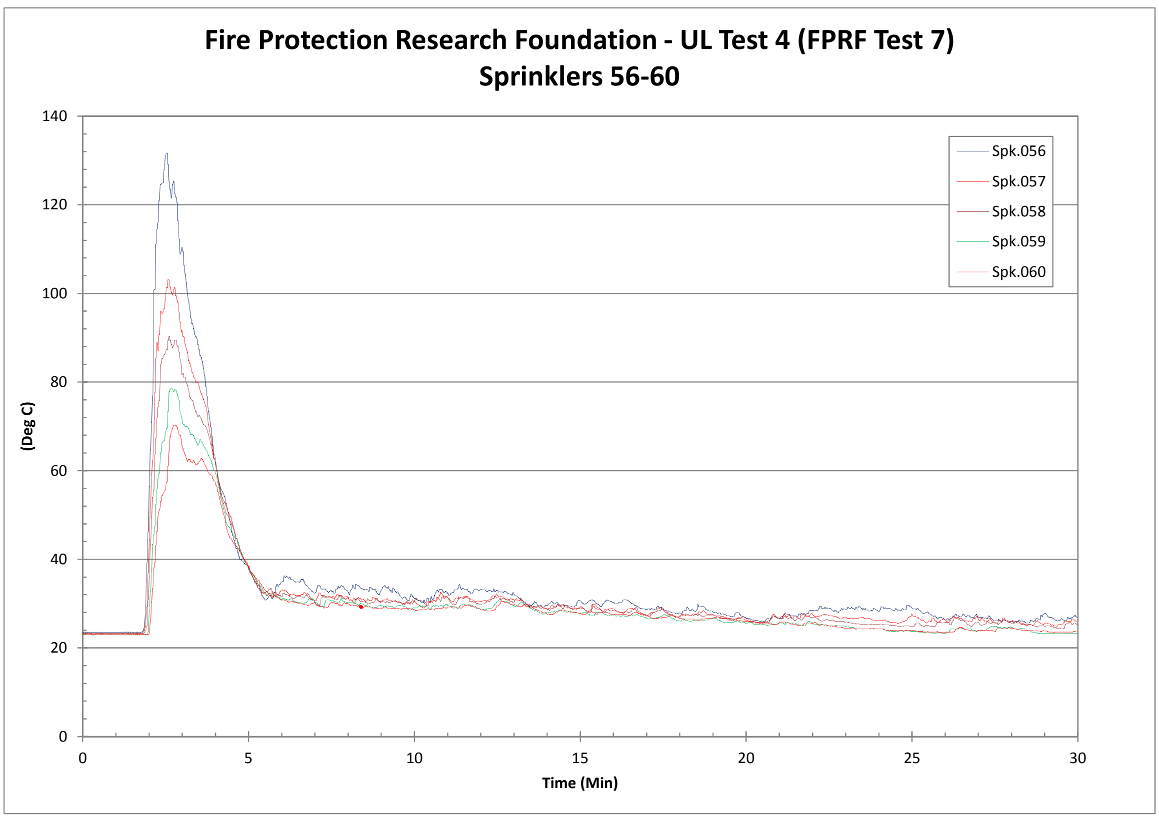

Fire Protection Research Foundation - UL Test 4 (FPRF Test 7)
Sprinklers 31-35
(Deg C)
Time (Min)
Spk.031
Spk.032
Spk.033
Spk.034
Spk.035
0
5
10
15
20
25
30
35
40
45

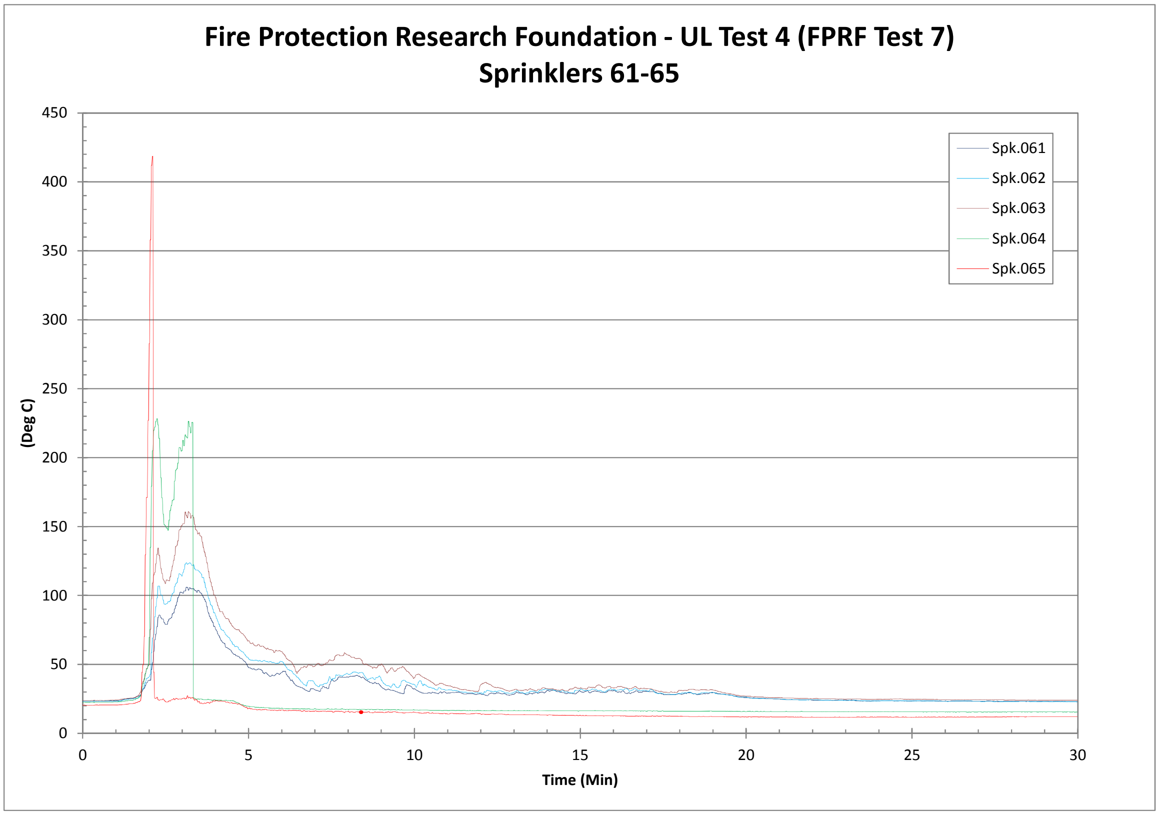

Fire Protection Research Foundation - UL Test 4 (FPRF Test 7)
Sprinklers 36-40
(Deg C)
Time (Min)
Spk.036
Spk.037
Spk.038
Spk.039
Spk.040
0
20
40
60
80
100
120
140
160

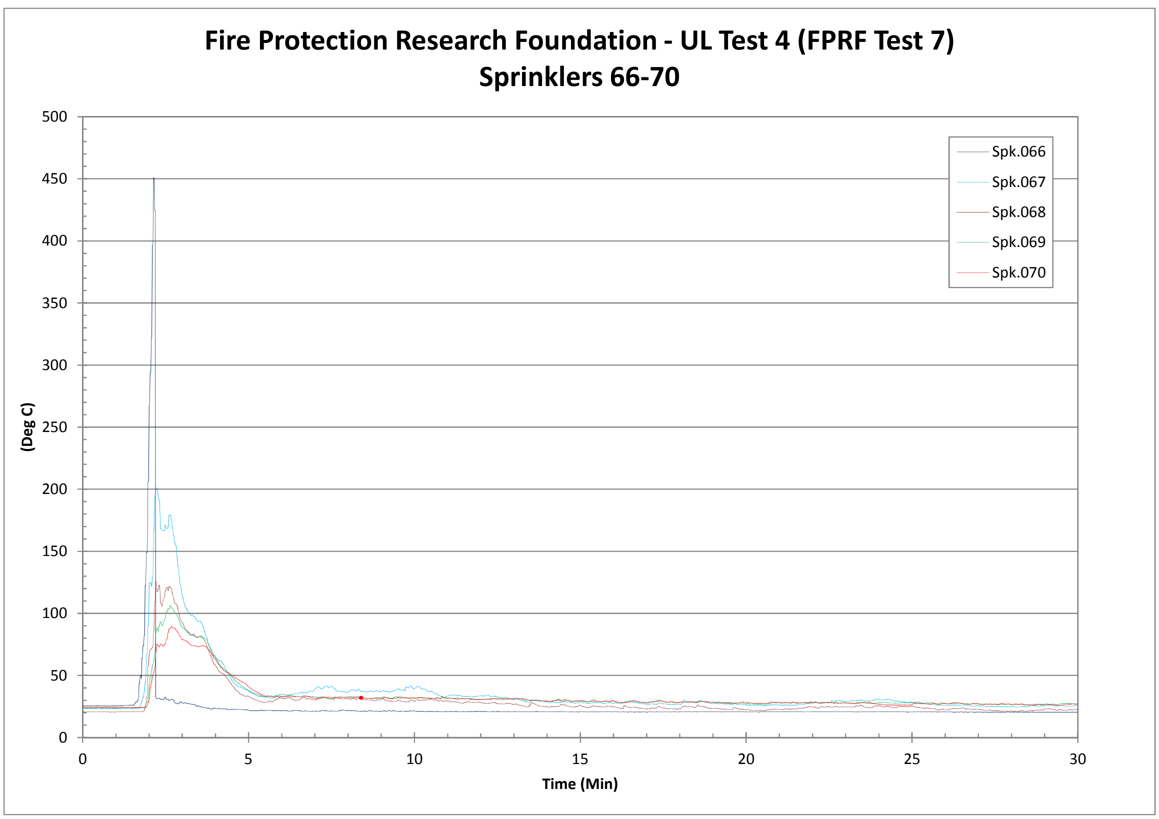

Fire Protection Research Foundation - UL Test 4 (FPRF Test 7)
Sprinklers 41-45
(Deg C)
250
200
150
100
50
0
0
5
10
15
20
25
30
Time (Min)
Spk.041
Spk.042
Spk.043
Spk.044
Spk.045

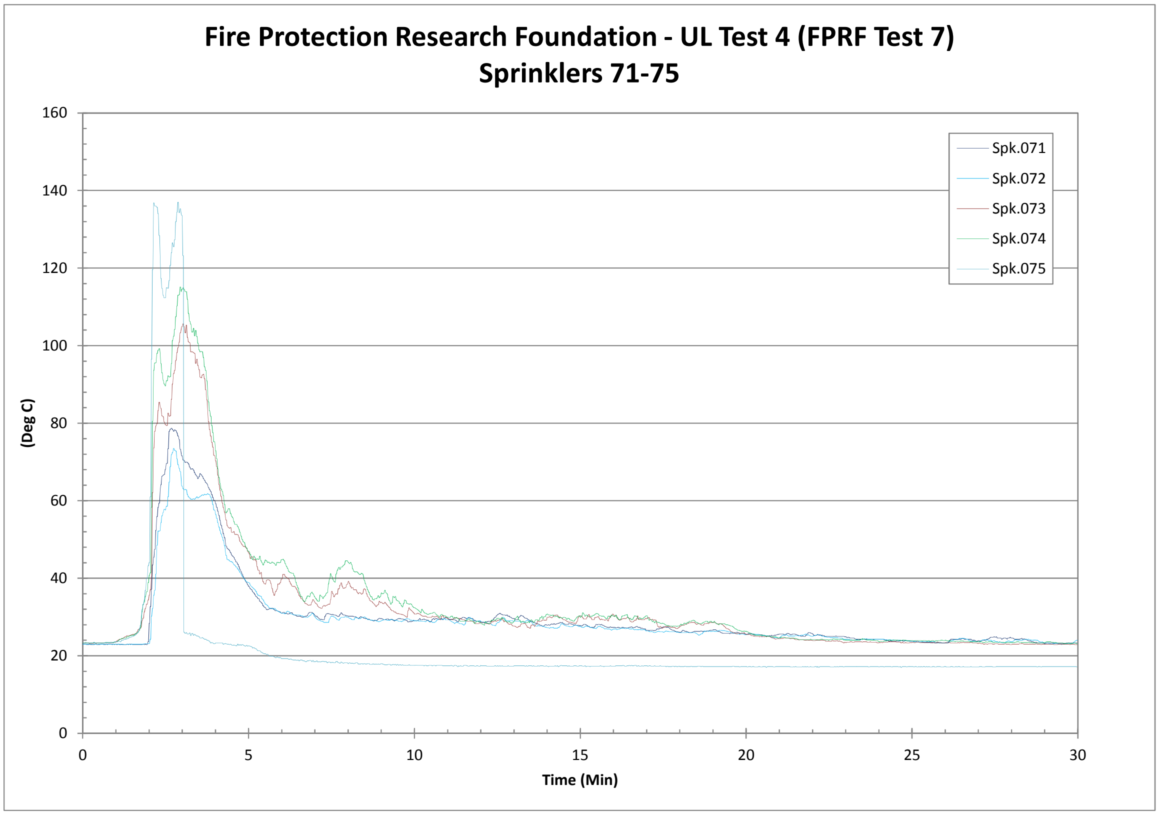

Fire Protection Research Foundation - UL Test 4 (FPRF Test 7
Sprinklers 46-50
(Deg C)
140
120
100
80
60
40
20
0
0
5
10
15
20
25
30
Time (Min)
Spk.046
Spk.047
Spk.048
Spk.049
Spk.050

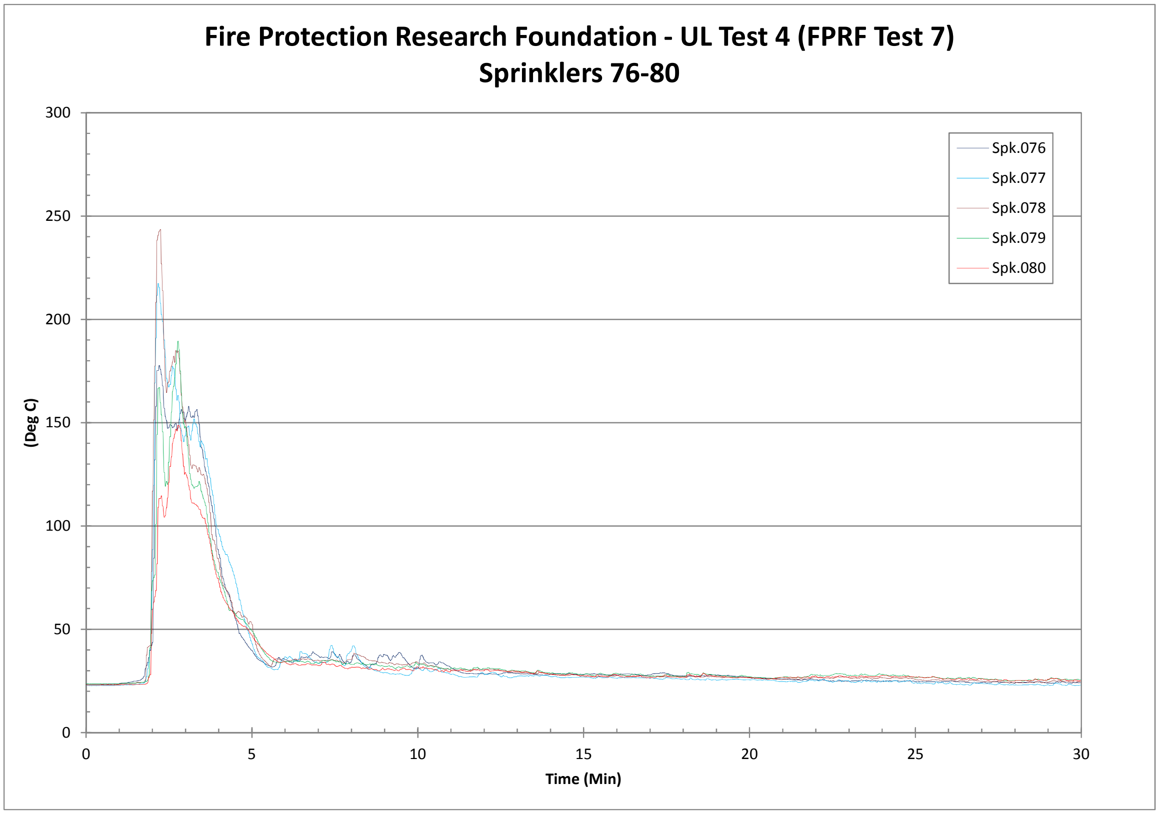

Fire Protection Research Foundation - UL Test 4 (FPRF Test 7)
Sprinklers 51-55
(Deg C)
Time (Min)
Spk.051
Spk.052
Spk.053
Spk.054
Spk.055
0
50
100
150
200
250
300
350
400
450
5
10
15
20
25
30

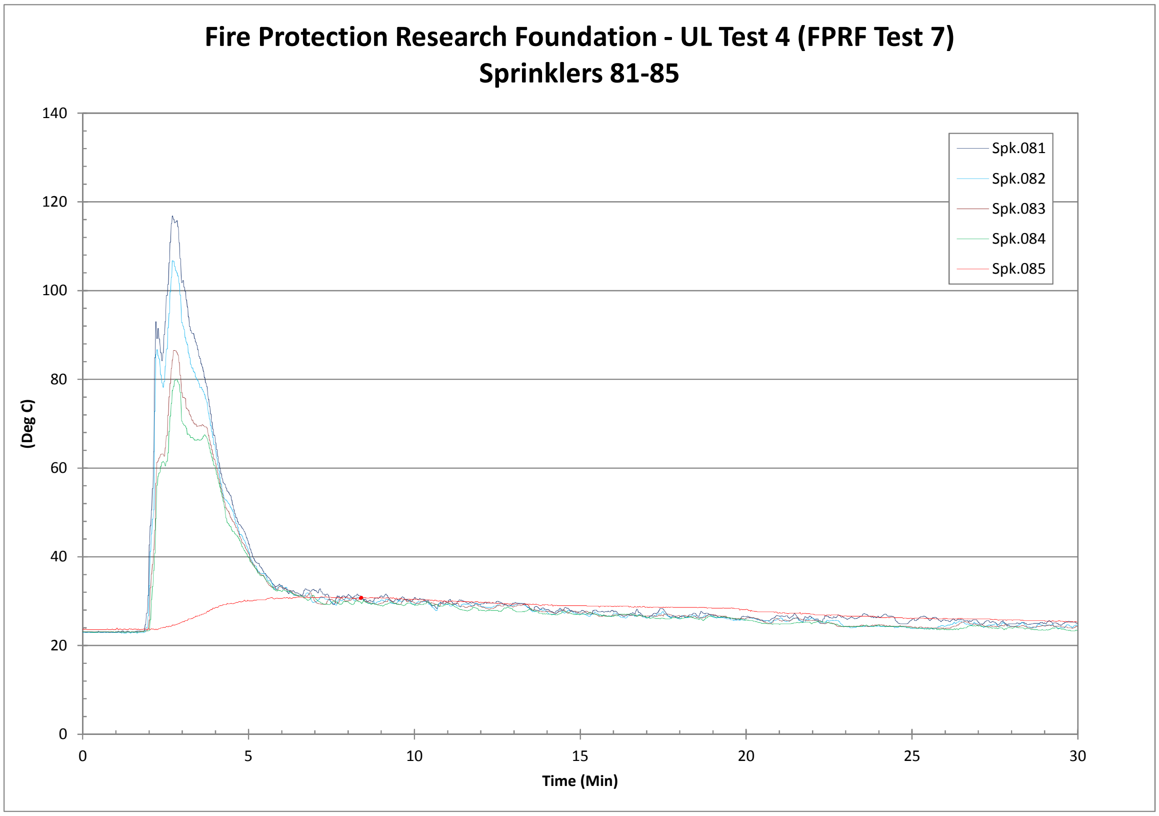

Fire Protection Research Foundation - UL Test 4 (FPRF Test 7)
Sprinklers 56-60
(Deg C)
Time (Min)
Spk.056
Spk.057
Spk.058
Spk.059
Spk.060
0
20
40
60
80
100
120
140
5
10
15
20
25
30

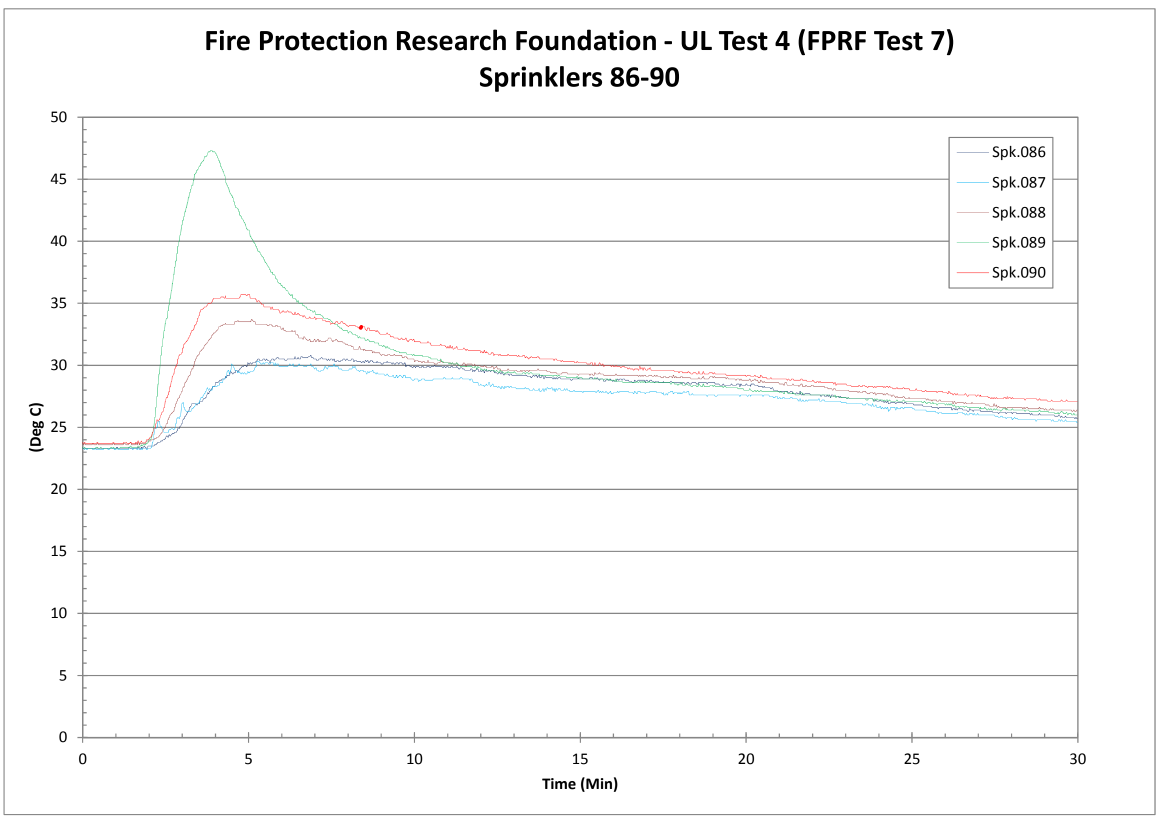

Fire Protection Research Foundation - UL Test 4 (FPRF Test 7)
Sprinklers 61-65
(Deg C)
Time (Min)
Spk.061
Spk.062
Spk.063
Spk.064
Spk.065

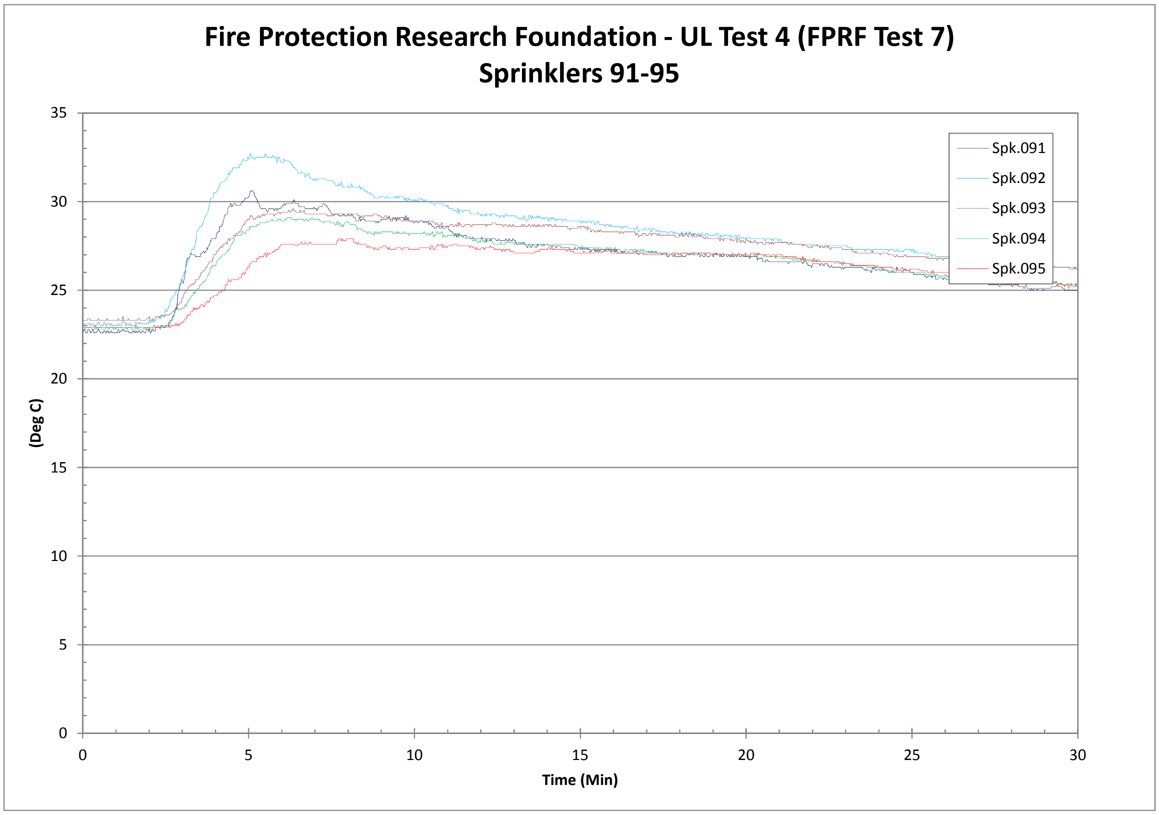

Fire Protection Research Foundation - UL Test 4 (FPRF Test 7)
Sprinklers 66-70
(Deg C)
Time (Min)
Spk.066
Spk.067
Spk.068
Spk.069
Spk.070

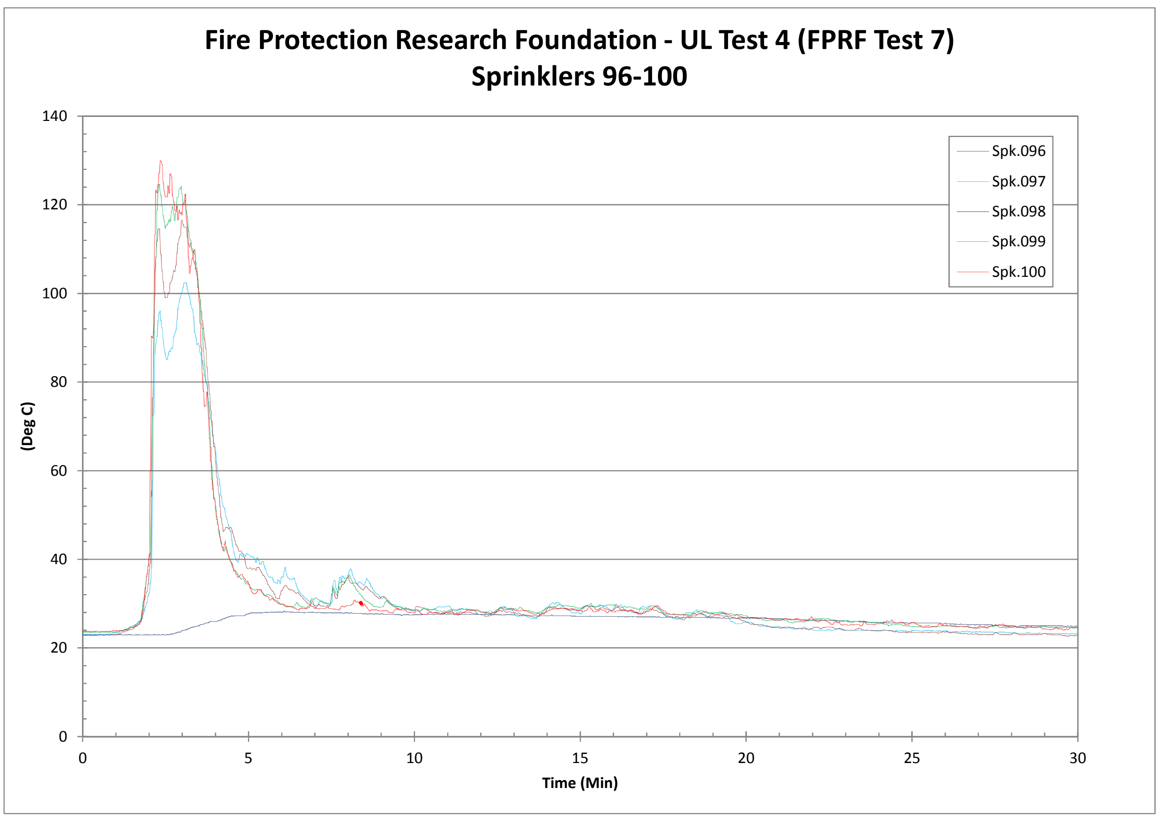

Fire Protection Research Foundation - UL Test 4 (FPRF Test 7)
Sprinklers 71-75
(Deg C)
Time (Min)
Spk.071
Spk.072
Spk.073
Spk.074
Spk.075
0
20
40
60
80
100
120
140
160
0
5
10
15
20
25
30

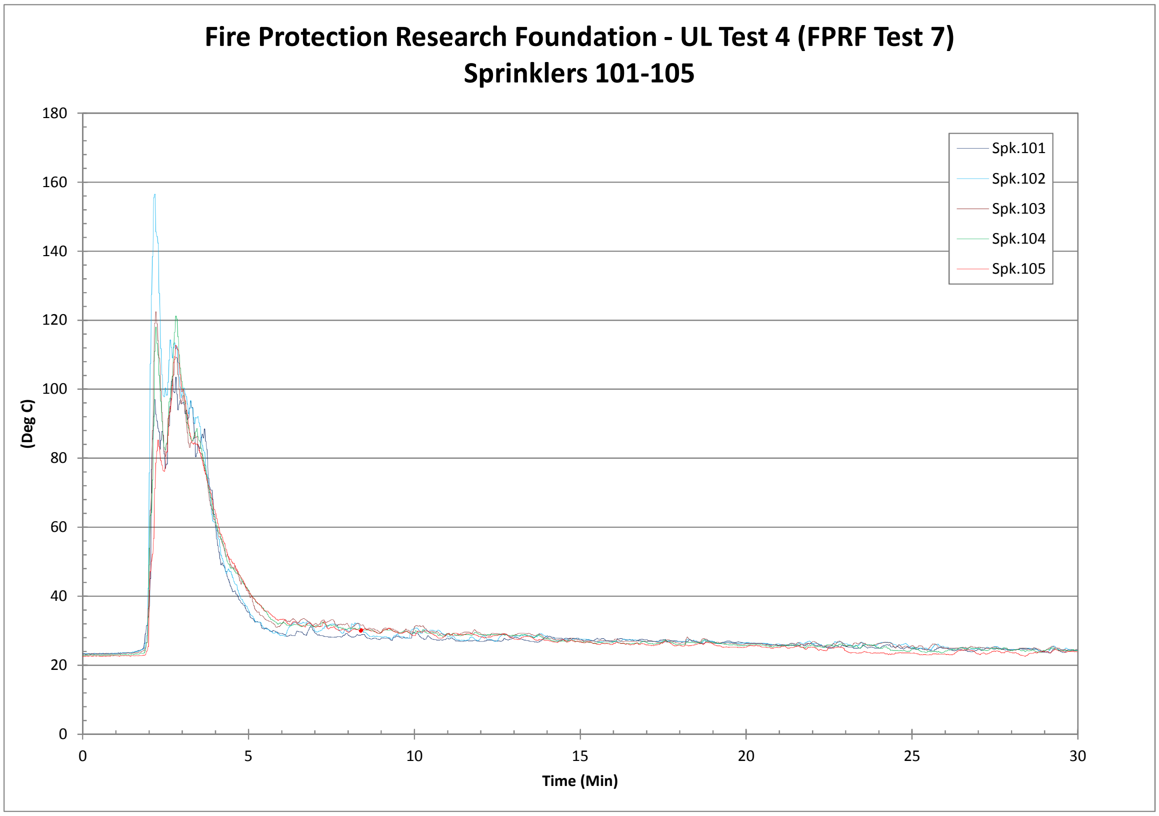

Fire Protection Research Foundation - UL Test 4 (FPRF Test 7)
Sprinklers 76-80
(Deg C)
Time (Min)
Spk.076
Spk.077
Spk.078
Spk.079
Spk.080
0
50
100
150
200
250
300
0
5
10
15
20
25
30

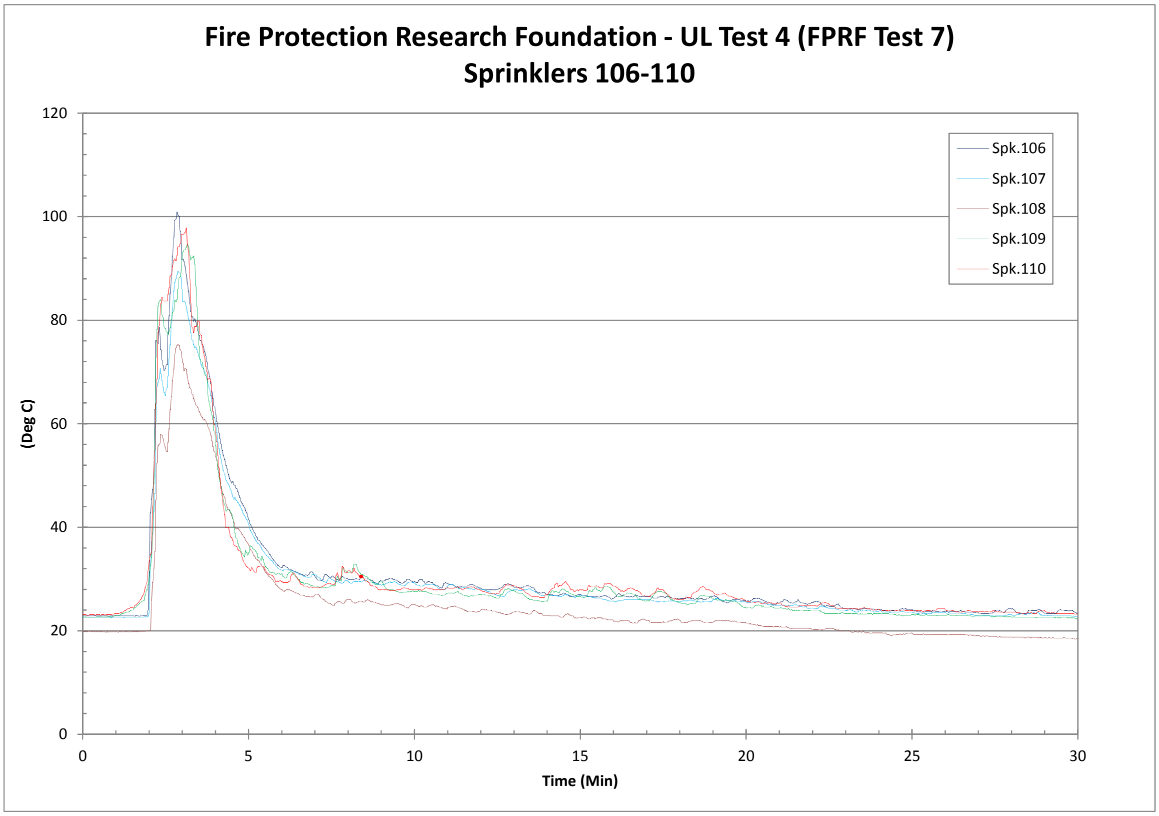

Fire Protection Research Foundation - UL Test 4 (FPRF Test 7)
Sprinklers 81-85
140
120
100
80
60
40
20
0
(Deg C)
0
5
10
15
20
25
30
Time (Min)
Spk.081
Spk.082
Spk.083
Spk.084
Spk.085

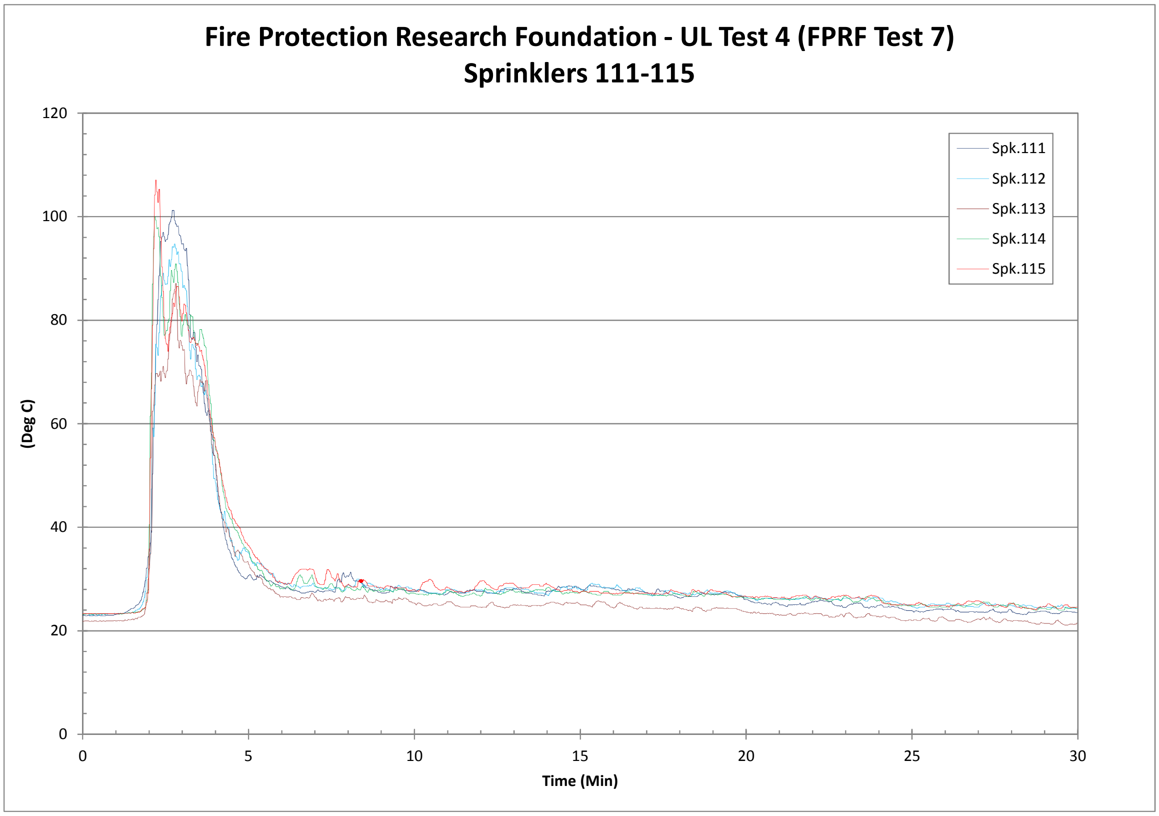

Fire Protection Research Foundation - UL Test 4 (FPRF Test 7)
Sprinklers 86-90
50
45
40
35
30
25
20
15
10
5
0
(Deg C)
0
5
10
15
20
25
30
Time (Min)
Spk.086
Spk.087
Spk.088
Spk.089
Spk.090

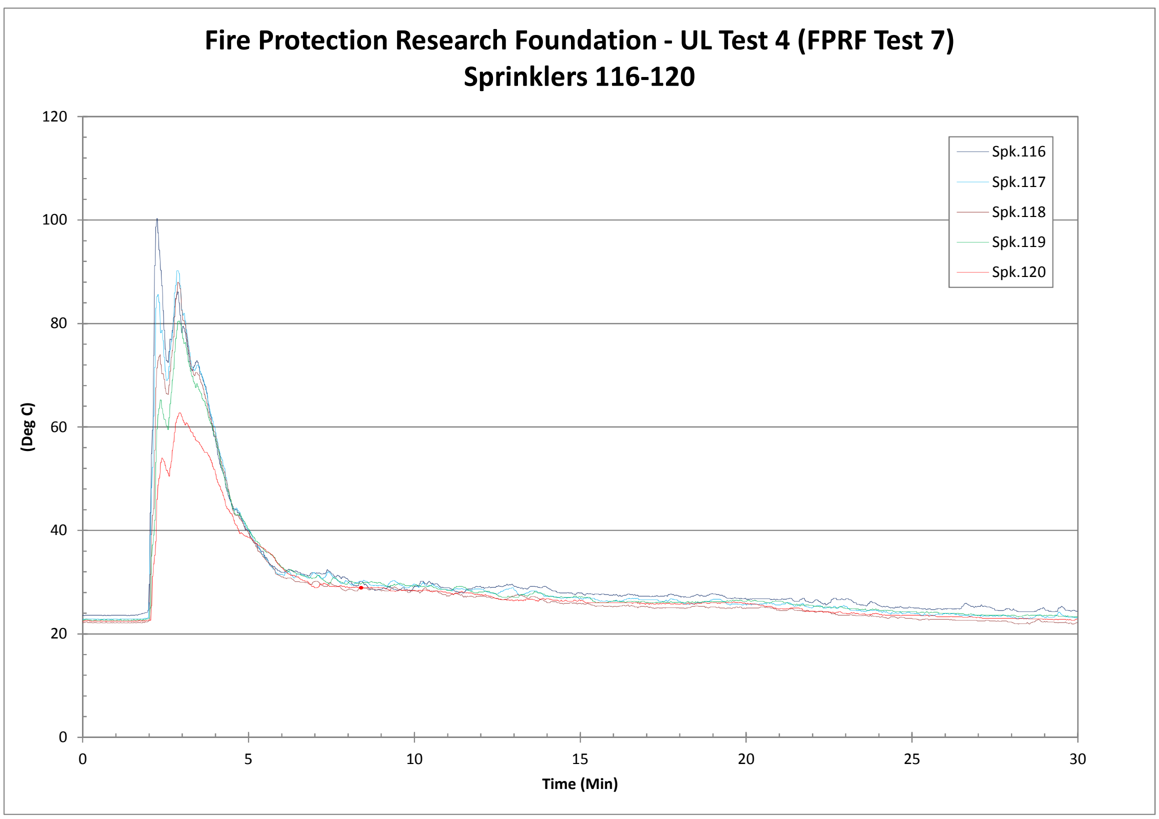

Fire Protection Research Foundation - UL Test 4 (FPRF Test 7)
Sprinklers 91-95
(Deg C)
Time (Min)
0
5
10
15
20
25
30
35
Spk.091
Spk.092
Spk.093
Spk.094
Spk.095

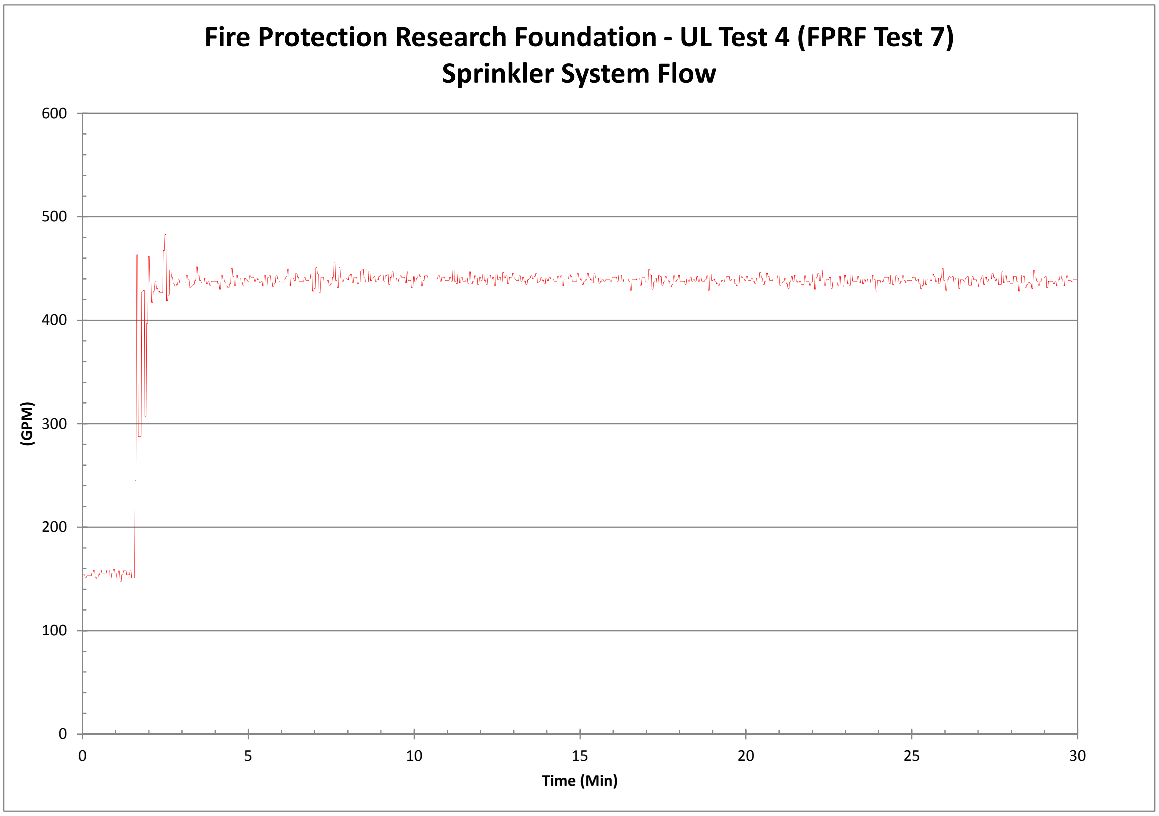

Fire Protection Research Foundation - UL Test 4 (FPRF Test 7)
Sprinklers 96-100
(Deg C)
Time (Min)
0
20
40
60
80
100
120
140
5
10
15
25
30
Spk.096
Spk.097
Spk.098
Spk.099
Spk.100

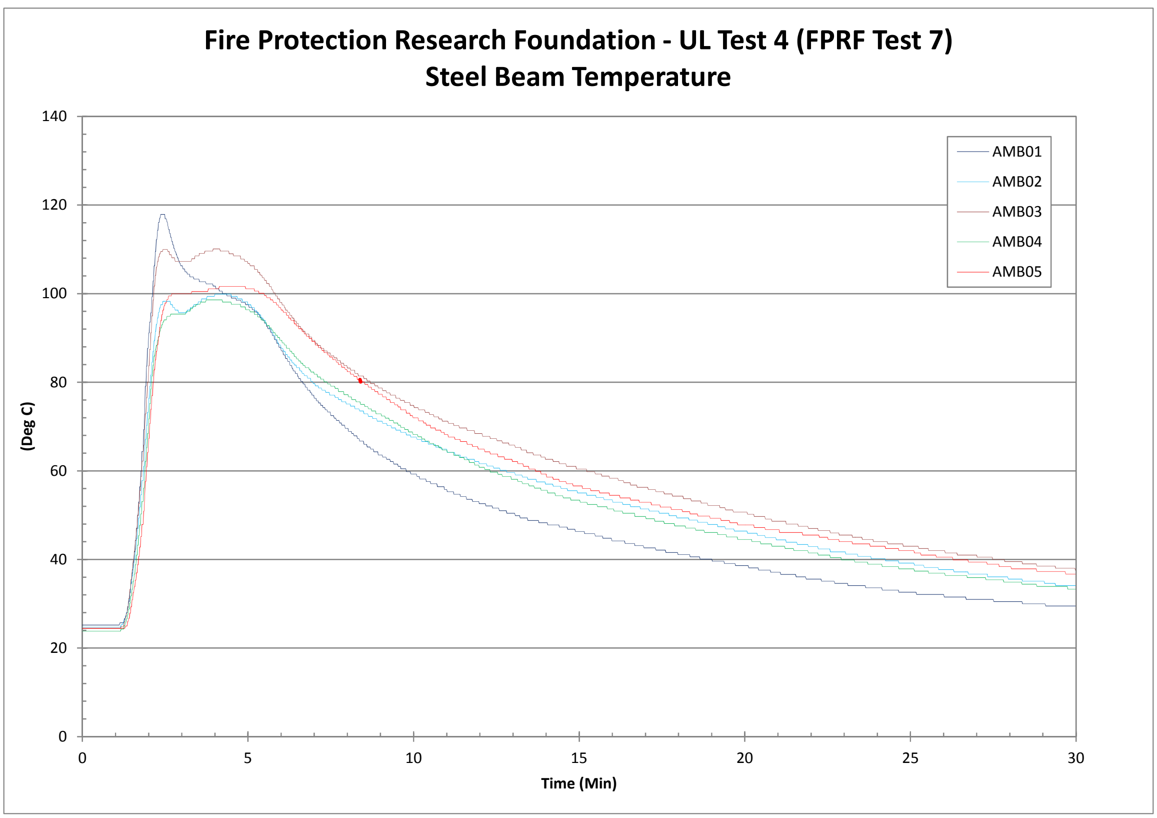

Fire Protection Research Foundation - UL Test 4 (FPRF Test 7)
Sprinklers 101-105
(Deg C)
Time (Min)
Spk.101
Spk.102
Spk.103
Spk.104
Spk.105
0
20
40
60
80
100
120
140
160
180
0
5
10
15
20
25
30

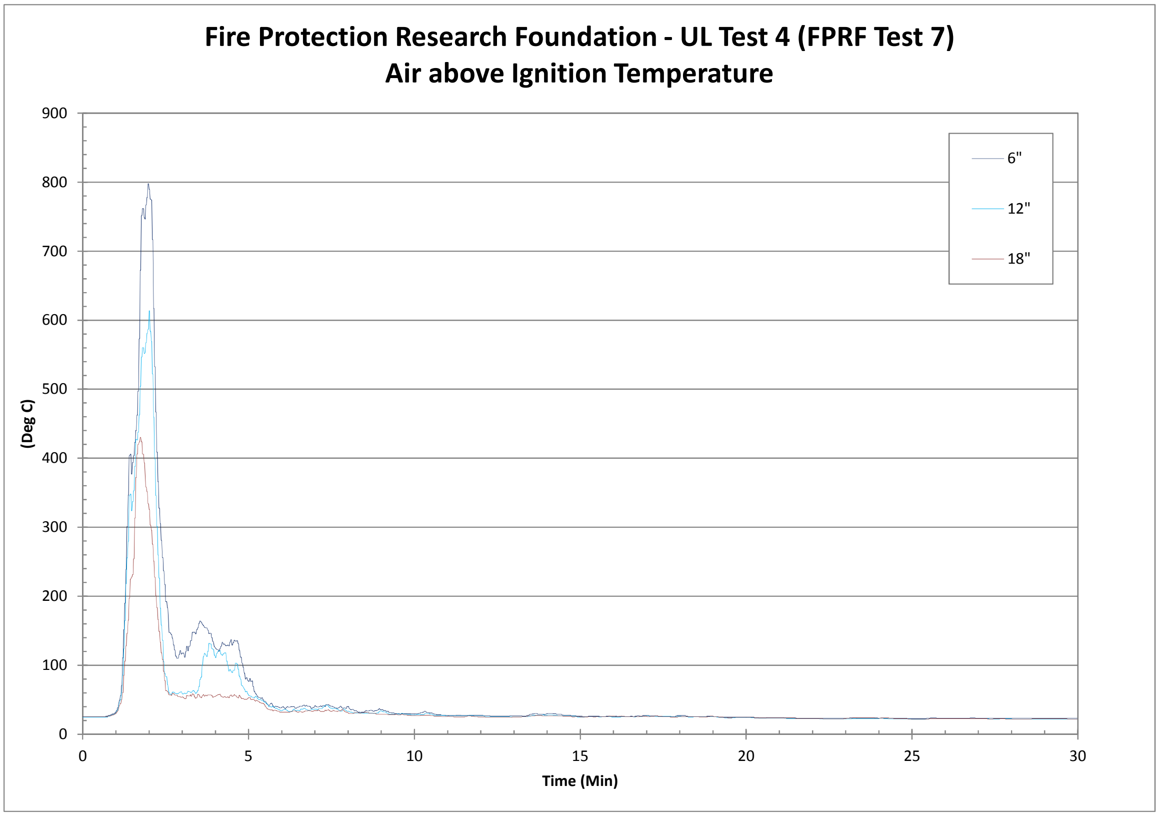

Fire Protection Research Foundation - UL Test 4 (FPRF Test 7)
Sprinklers 106-110
(Deg C)
Time (Min)
Spk.106
Spk.107
Spk.108
Spk.109
Spk.110
0
20
40
60
80
100
120
0
5
10
15
20
25
30

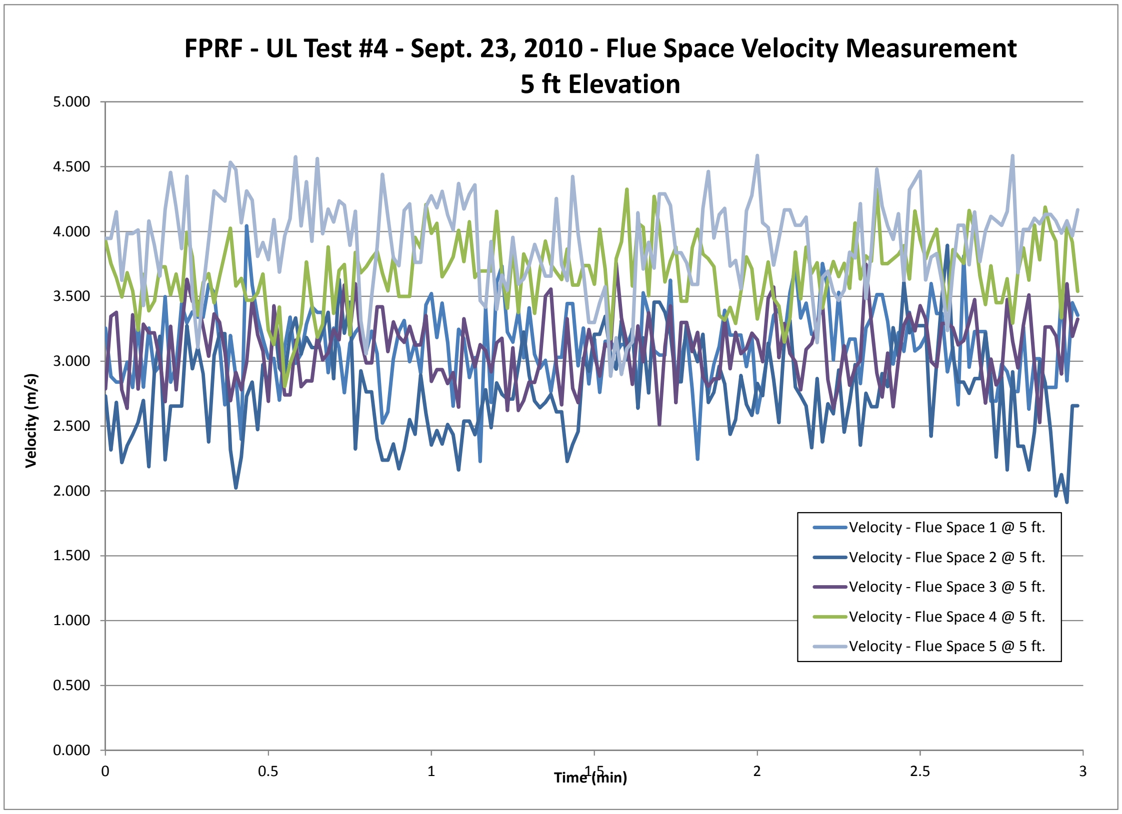

Fire Protection Research Foundation - UL Test 4 (FPRF Test 7)
Sprinklers 111-115
(Deg C)
Time (Min)
Spk.111
Spk.112
Spk.113
Spk.114
Spk.115
0
20
40
60
80
100
120
0
5
10
15
20
25
30

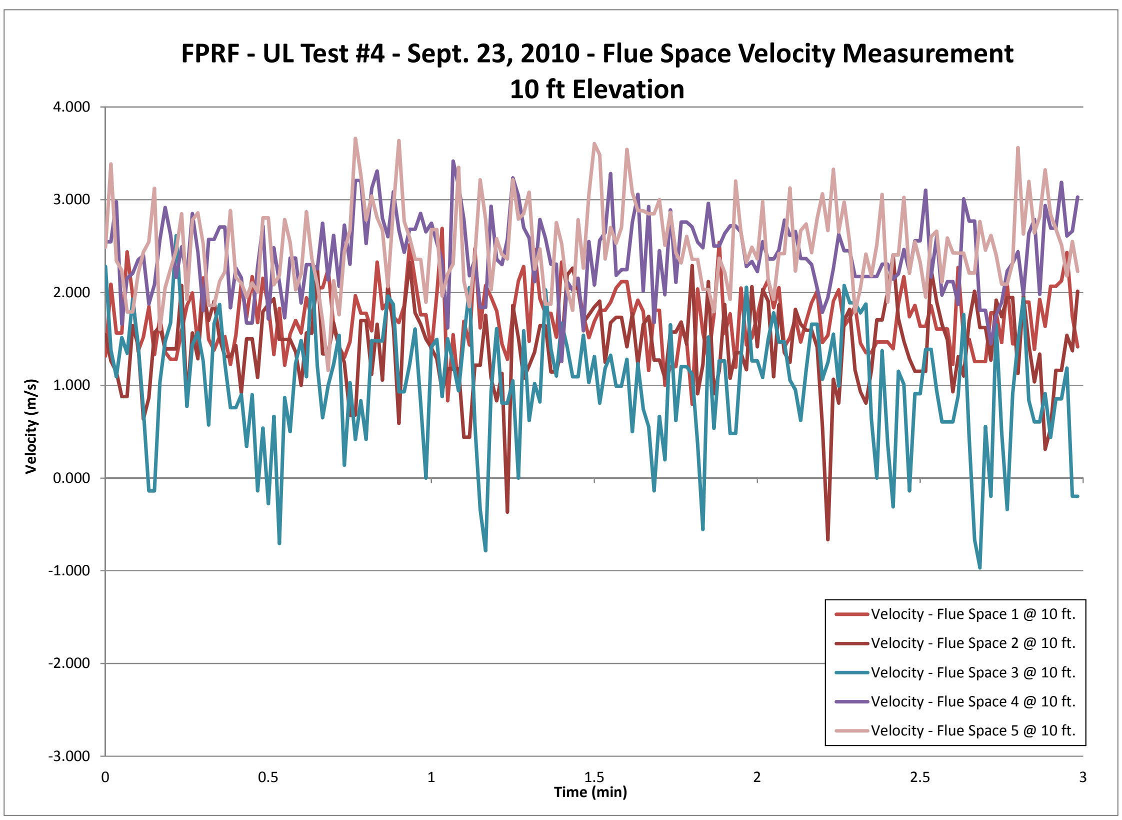

Fire Protection Research Foundation - UL Test 4 (FPRF Test 7)
Sprinklers 116-120
(Deg C)
Time (Min)
Spk.116
Spk.117
Spk.118
Spk.119
Spk.120
0
20
40
60
80
100
120
0
5
10
15
20
25
30

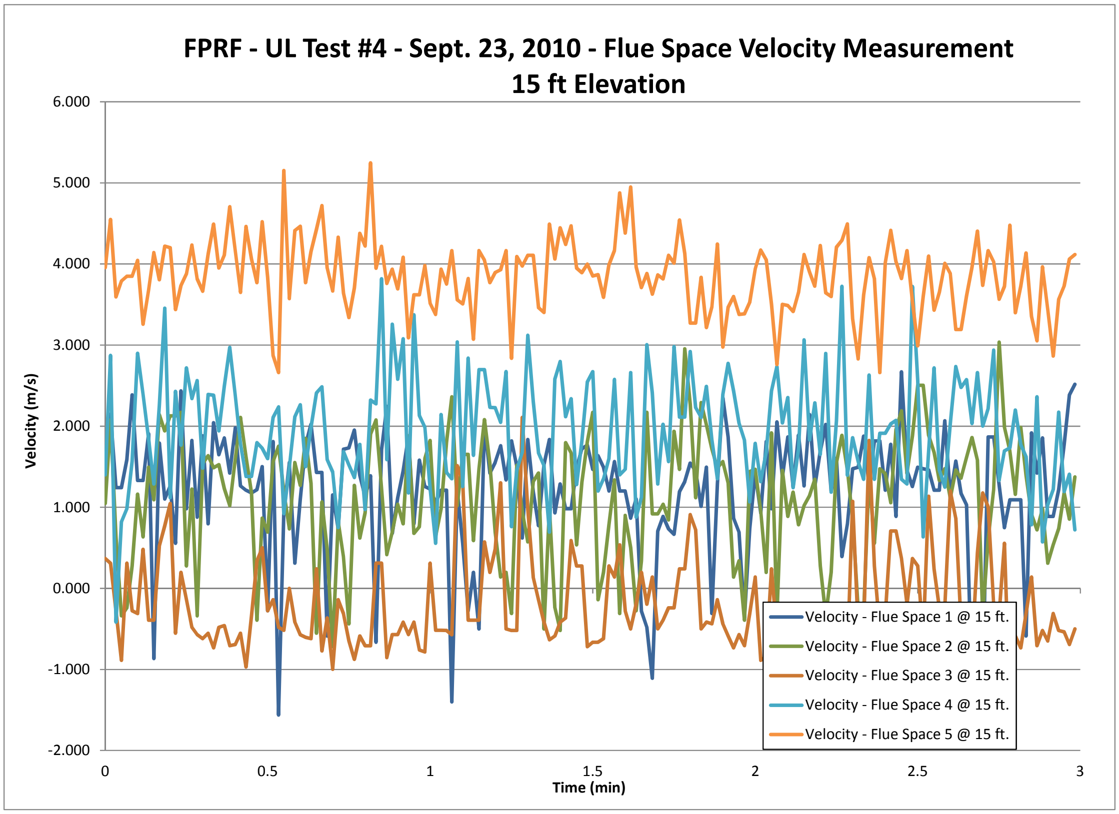

Fire Protection Research Foundation - UL Test 4 (FPRF Test 7)
Sprinkler System Flow
(GPM)
0
100
200
300
400
500
600
0
5
10
15
20
25
30
Time (Min)

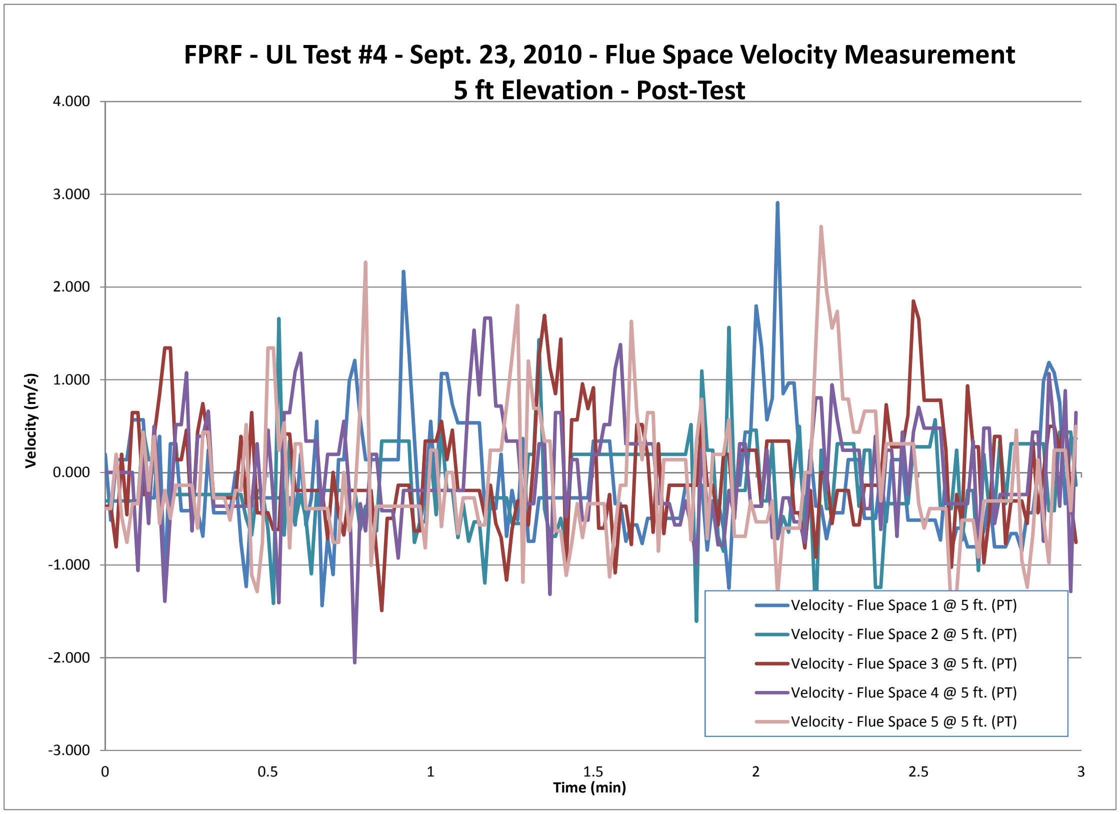

Fire Protection Research Foundation - UL Test 4 (FPRF Test 7)
Steel Beam Temperature
(Deg C)
0
20
40
60
80
100
120
140
0
5
10
15
20
25
30
Time (Min)
AMB01
AMB02
AMB03
AMB04
AMB05

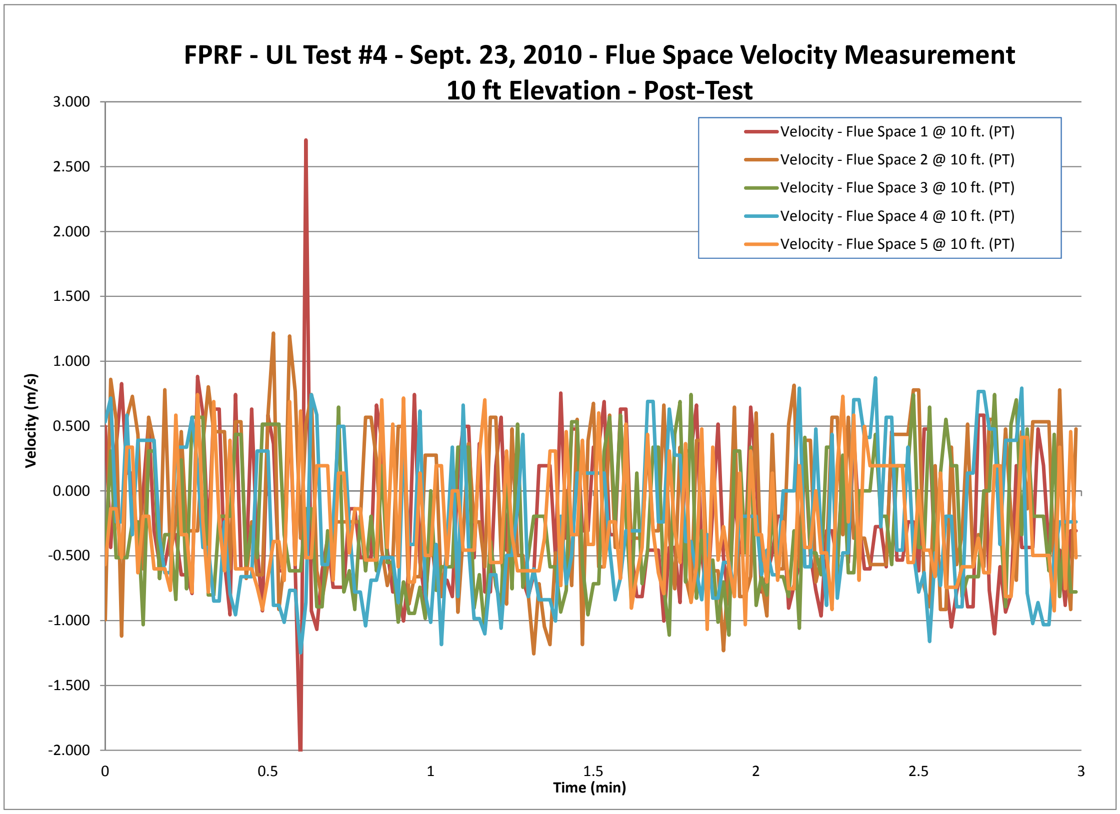

Fire Protection Research Foundation - UL Test 4 (FPRF Test 7)
Air above Ignition Temperature
(Deg C)
Time (Min)
6"
12"
18"
0
100
200
300
400
500
600
700
800
900
0
5
10
15
20
25
30

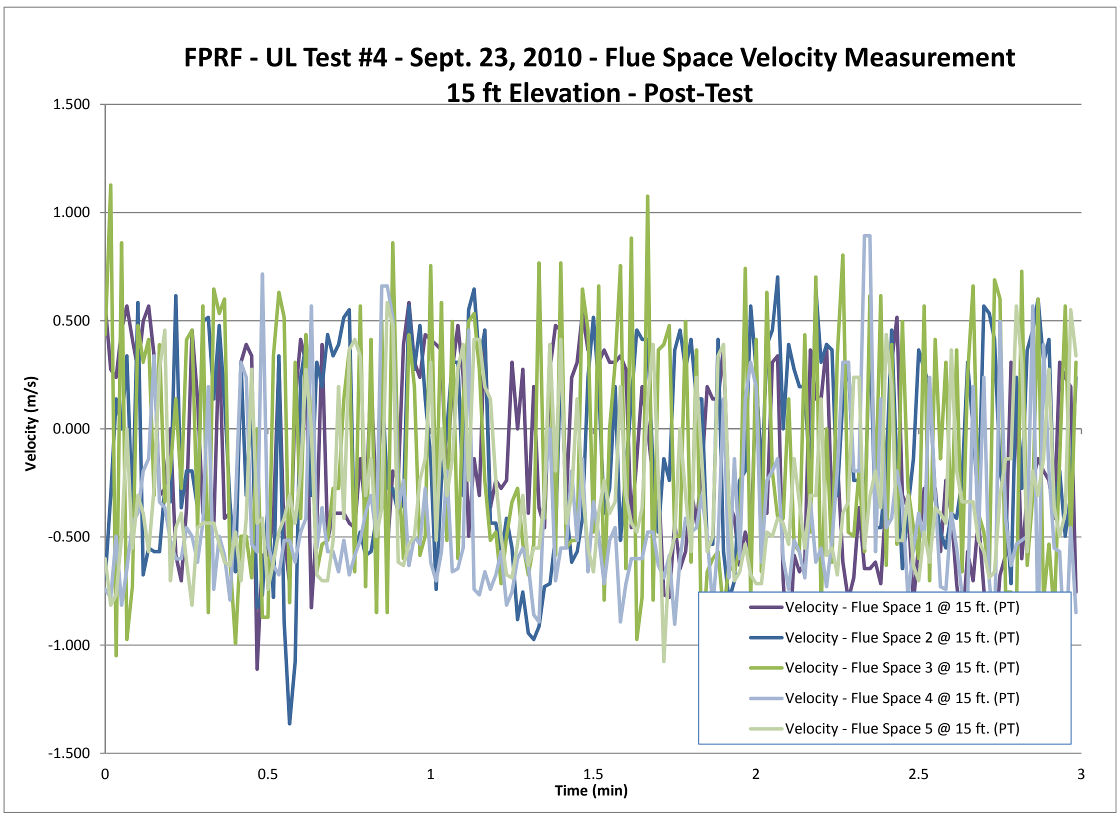

FPRF - UL Test #4 - Sept. 23, 2010 - Flue Space Velocity Measurement
5 ft Elevation
Velocity (m/s)
Time (min)
Velocity - Flue Space 1 @ 5 ft.
Velocity - Flue Space 2 @ 5 ft.
Velocity - Flue Space 3 @ 5 ft.
Velocity - Flue Space 4 @ 5 ft.
Velocity - Flue Space 5 @ 5 ft.


FPRF - UL Test #4 - Sept. 23, 2010 - Flue Space Velocity Measurement
10 ft Elevation
Velocity (m/s)
Time (min)
Velocity - Flue Space 1 @ 10 ft.
Velocity - Flue Space 2 @ 10 ft.
Velocity - Flue Space 3 @ 10 ft.
Velocity - Flue Space 4 @ 10 ft.
Velocity - Flue Space 5 @ 10 ft.


FPRF - UL Test #4 - Sept. 23, 2010 - Flue Space Velocity Measurement
15 ft Elevation
Velocity (m/s)
Time (min)
6.000
5.000
4.000
3.000
2.000
1.000
0.000
-1.000
-2.000
0
0.5
1
1.5
2
2.5
3
Velocity - Flue Space 1 @ 15 ft.
Velocity - Flue Space 2 @ 15 ft.
Velocity - Flue Space 3 @ 15 ft.
Velocity - Flue Space 4 @ 15 ft.
Velocity - Flue Space 5 @ 15 ft.


FPRF - UL Test #4 - Sept. 23, 2010 - Flue Space Velocity Measurement
5 ft Elevation - Post-Test
Velocity (m/s)
Time (min)
4.000
3.000
2.000
1.000
0.000
-1.000
-2.000
-3.000
0
0.5
1
1.5
2
2.5
3
Velocity - Flue Space 1 @ 5 ft. (PT)
Velocity - Flue Space 2 @ 5 ft. (PT)
Velocity - Flue Space 3 @ 5 ft. (PT)
Velocity - Flue Space 4 @ 5 ft. (PT)
Velocity - Flue Space 5 @ 5 ft. (PT)


FPRF - UL Test #4 - Sept. 23, 2010 - Flue Space Velocity Measurement
10 ft Elevation - Post-Test
Velocity - Flue Space 1 @ 10 ft. (PT)
Velocity - Flue Space 2 @ 10 ft. (PT)
Velocity - Flue Space 3 @ 10 ft. (PT)
Velocity - Flue Space 4 @ 10 ft. (PT)
Velocity - Flue Space 5 @ 10 ft. (PT)
Velocity (m/s)
Time (min)
3.000
2.500
2.000
1.500
1.000
0.500
0.000
-0.500
-1.000
-1.500
-2.000
0
0.5
1
1.5
2
2.5
3

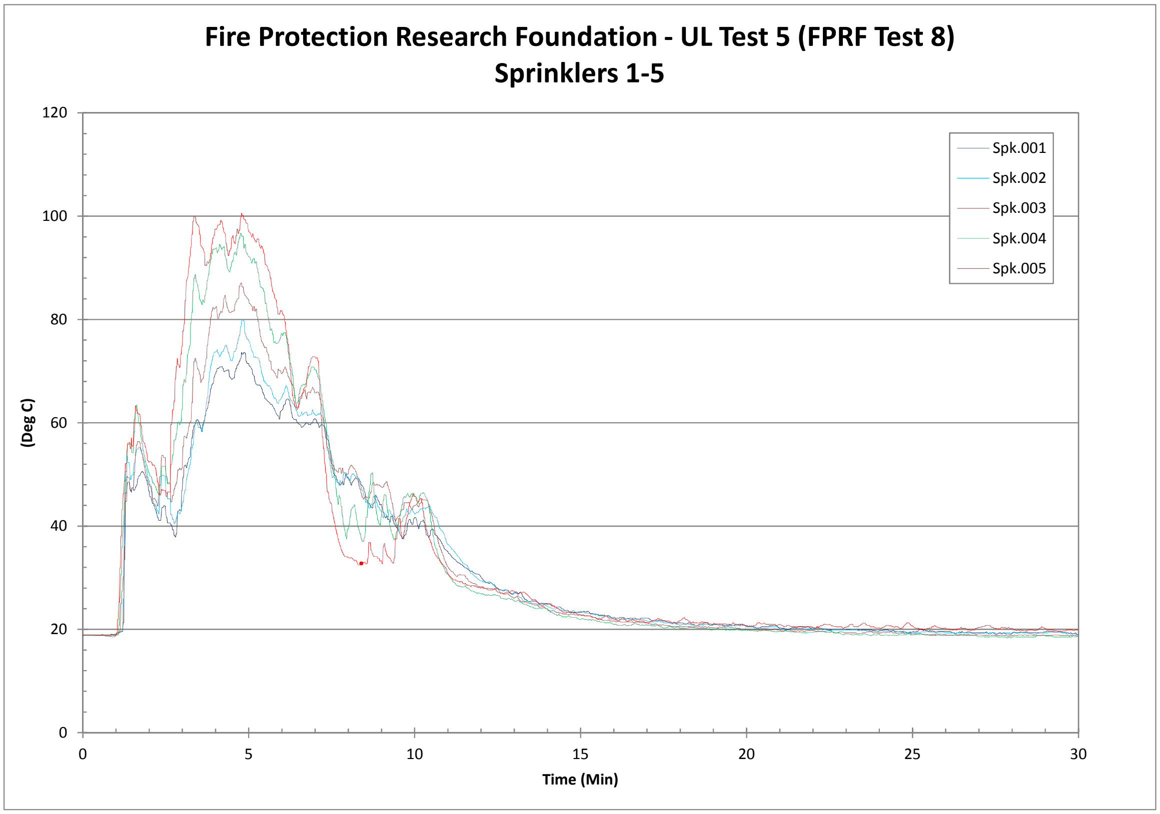

FPRF - UL Test #4 - Sept. 23, 2010 - Flue Space Velocity Measurement
15 ft Elevation - Post-Test
Velocity - Flue Space 1 @ 15 ft. (PT)
Velocity - Flue Space 2 @ 15 ft. (PT)
Velocity - Flue Space 3 @ 15 ft. (PT)
Velocity - Flue Space 4 @ 15 ft. (PT)
Velocity - Flue Space 5 @ 15 ft. (PT)
Velocity (m/s)
Time (min)
1.500
1.000
0.500
0.000
-0.500
-1.000
-1.500
0
0.5
1
1.5
2
2.5
3

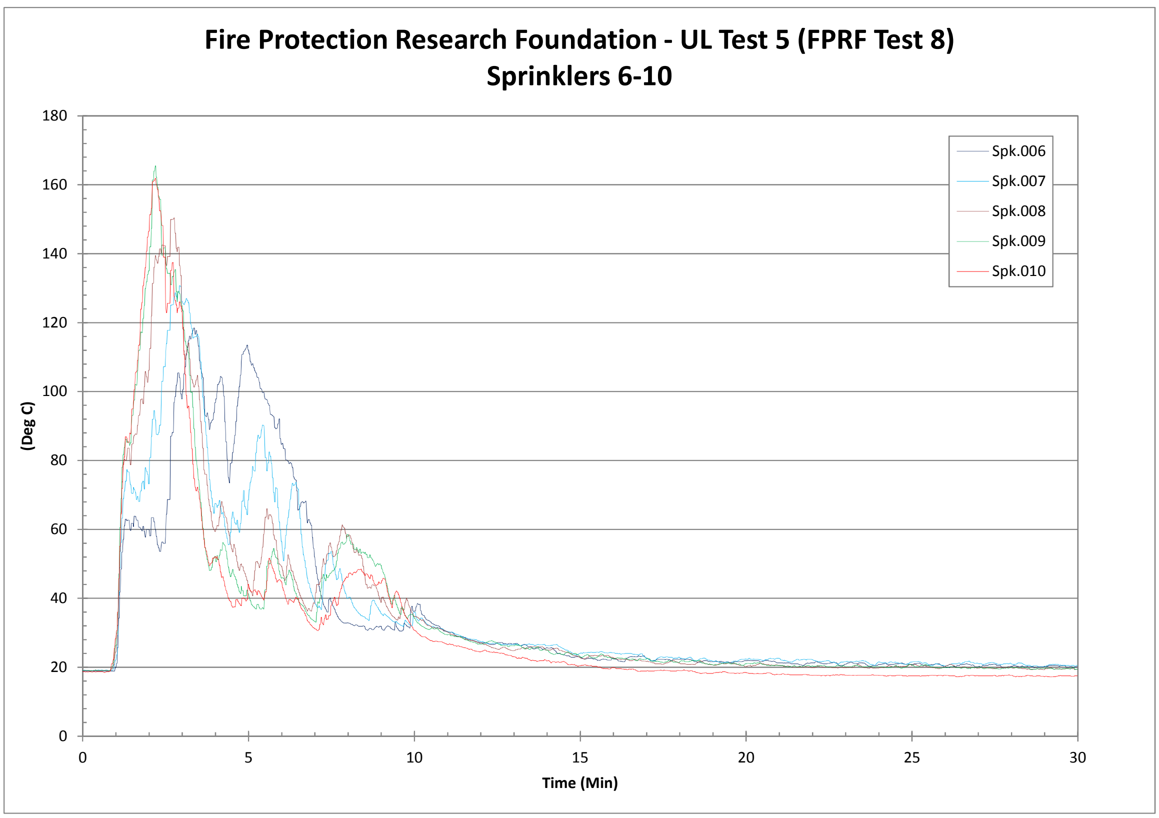
APPENDIX E

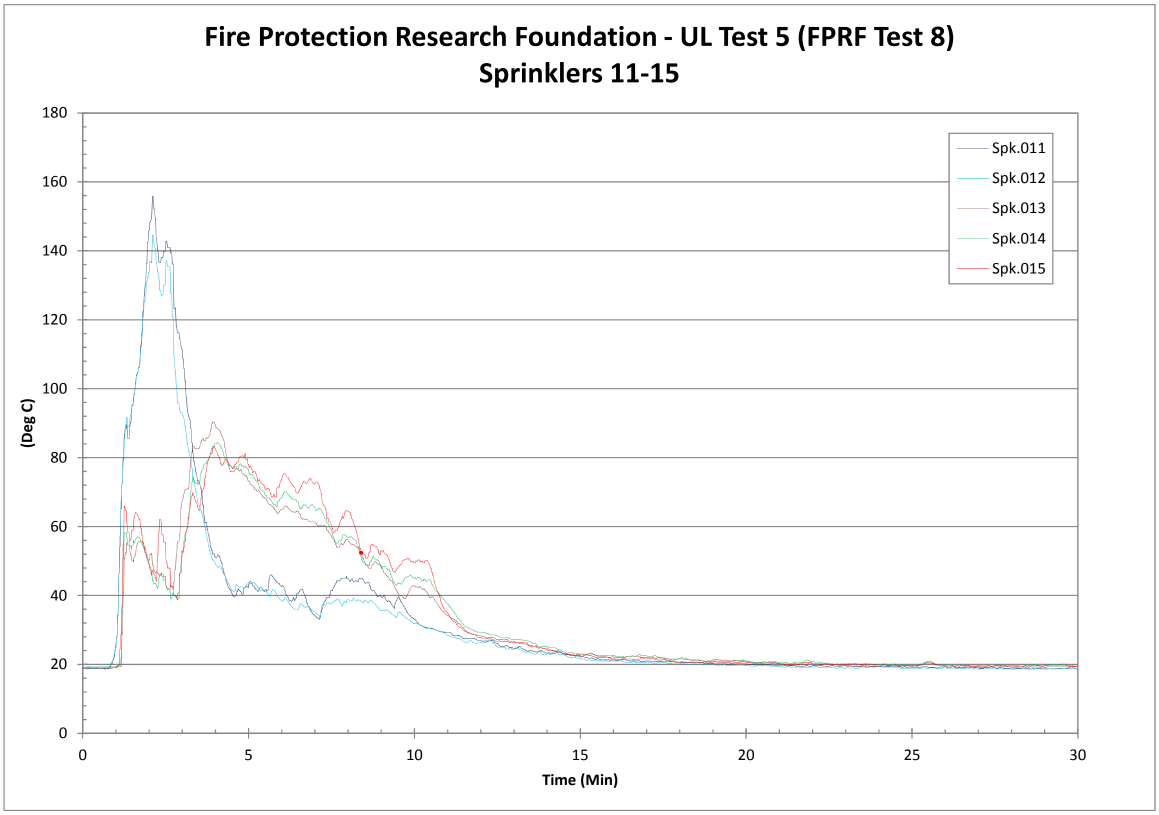
Graphical Presentation of

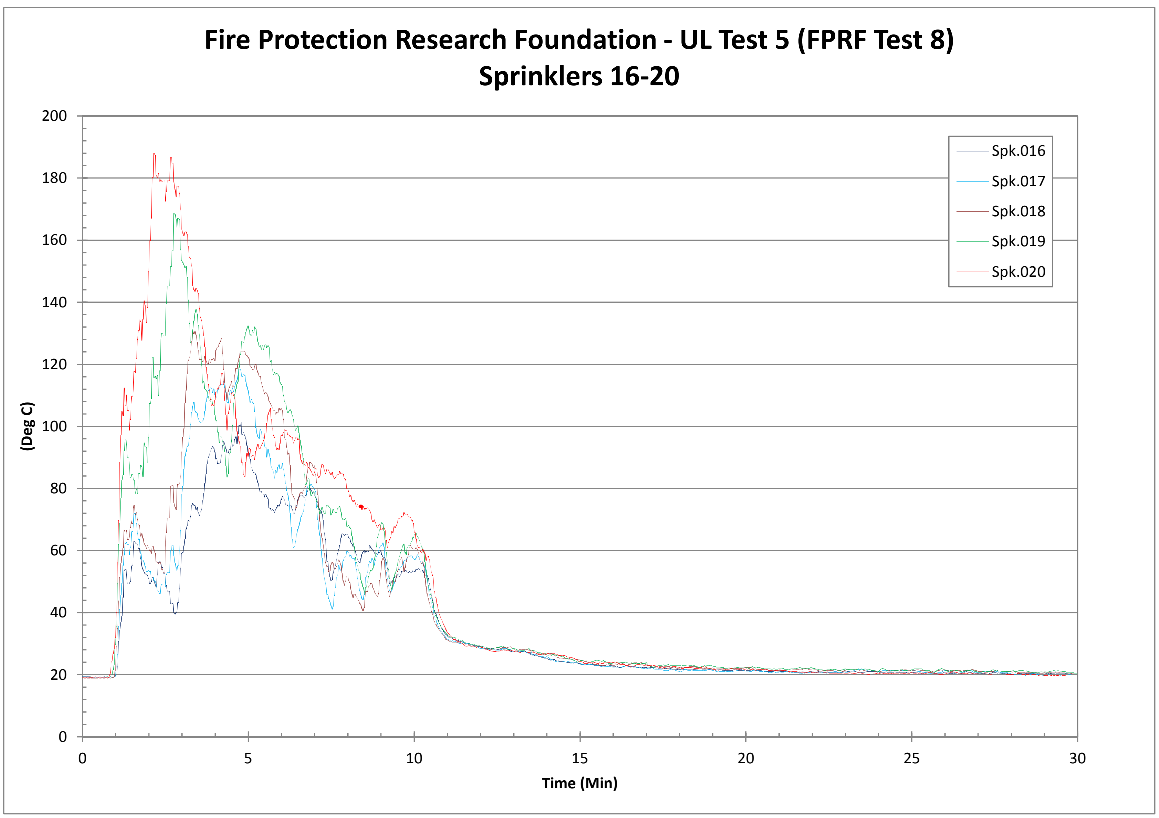
Gas Temperatures, Steel Temperatures, System Waterflow and Velocities - Test 5

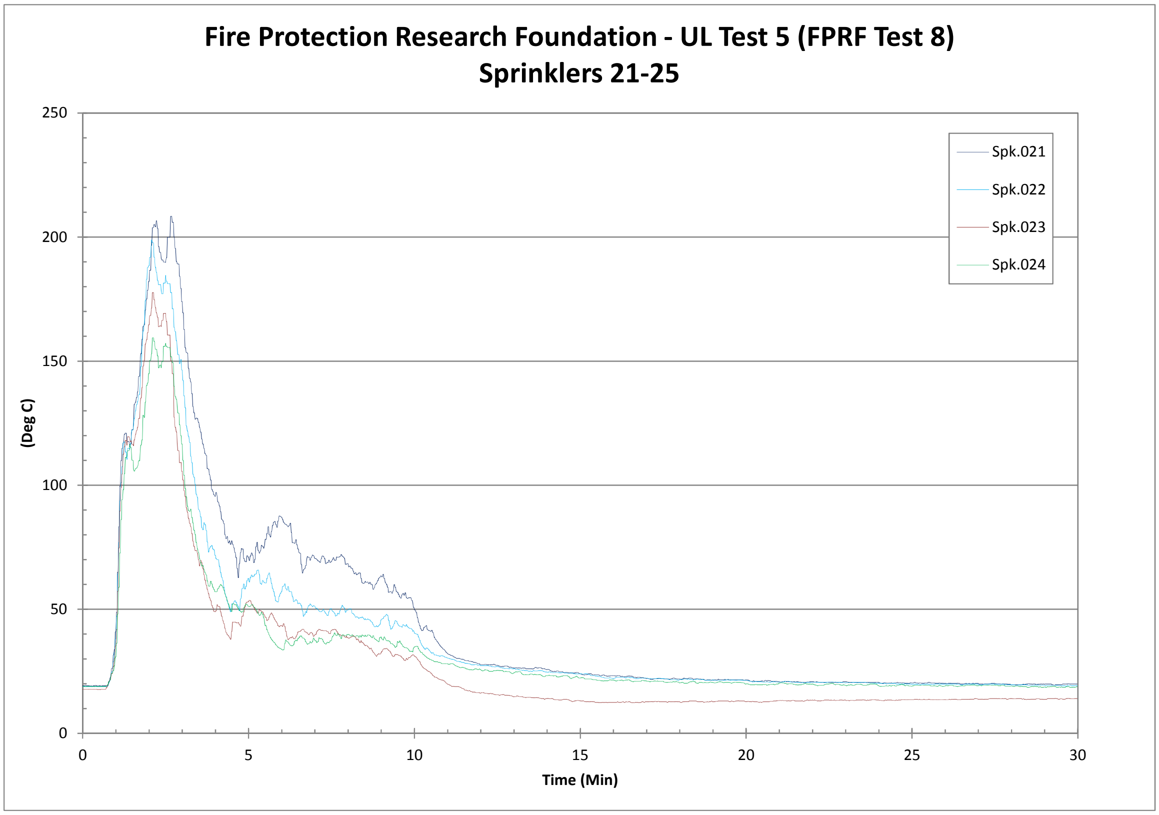
Index: Page

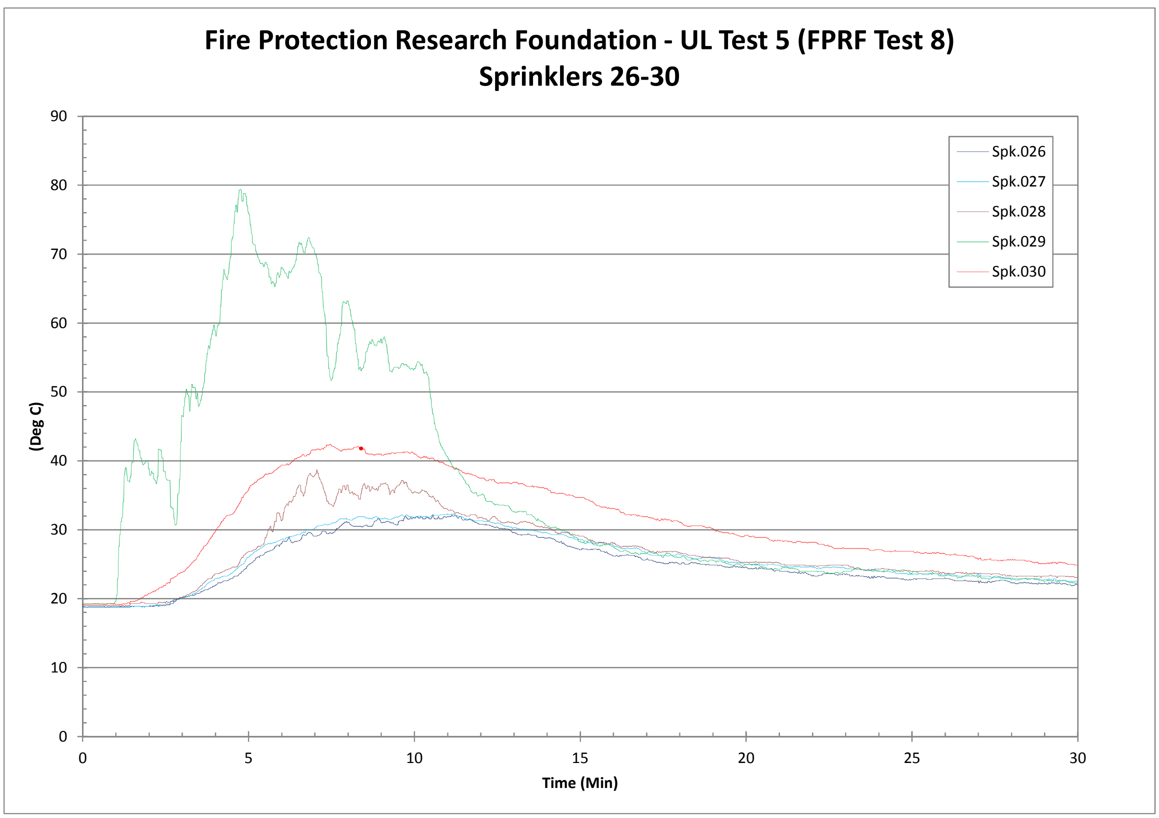

Fire Protection Research Foundation - UL Test 5 (FPRF Test 8)
Sprinklers 1-5
(Deg C)
Time (Min)
Spk.001
Spk.002
Spk.003
Spk.004
Spk.005
0
20
40
60
80
100
120
0
5
10
15
20
25
30

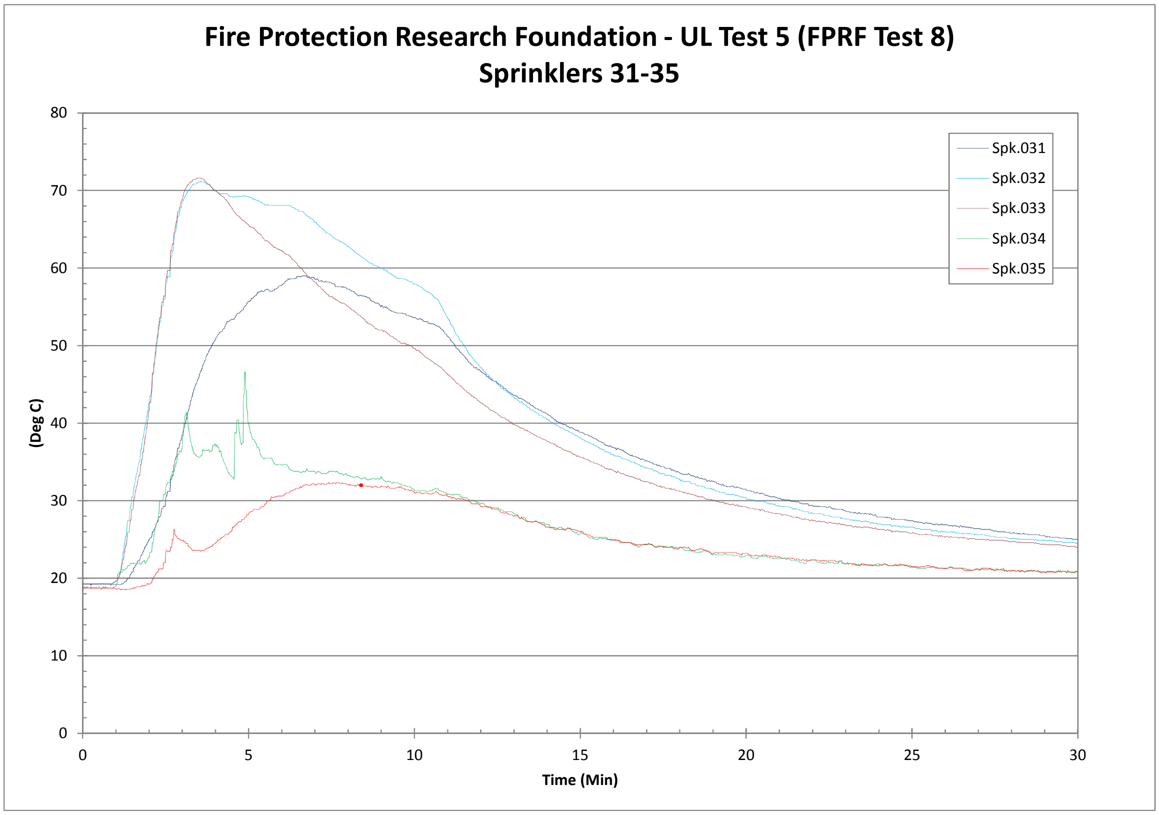

Fire Protection Research Foundation - UL Test 5 (FPRF Test 8)
Sprinklers 6-10
(Deg C)
Time (Min)
Spk.006
Spk.007
Spk.008
Spk.009
Spk.010
0
20
40
60
80
100
120
140
160
180
0
5
10
15
20
25
30

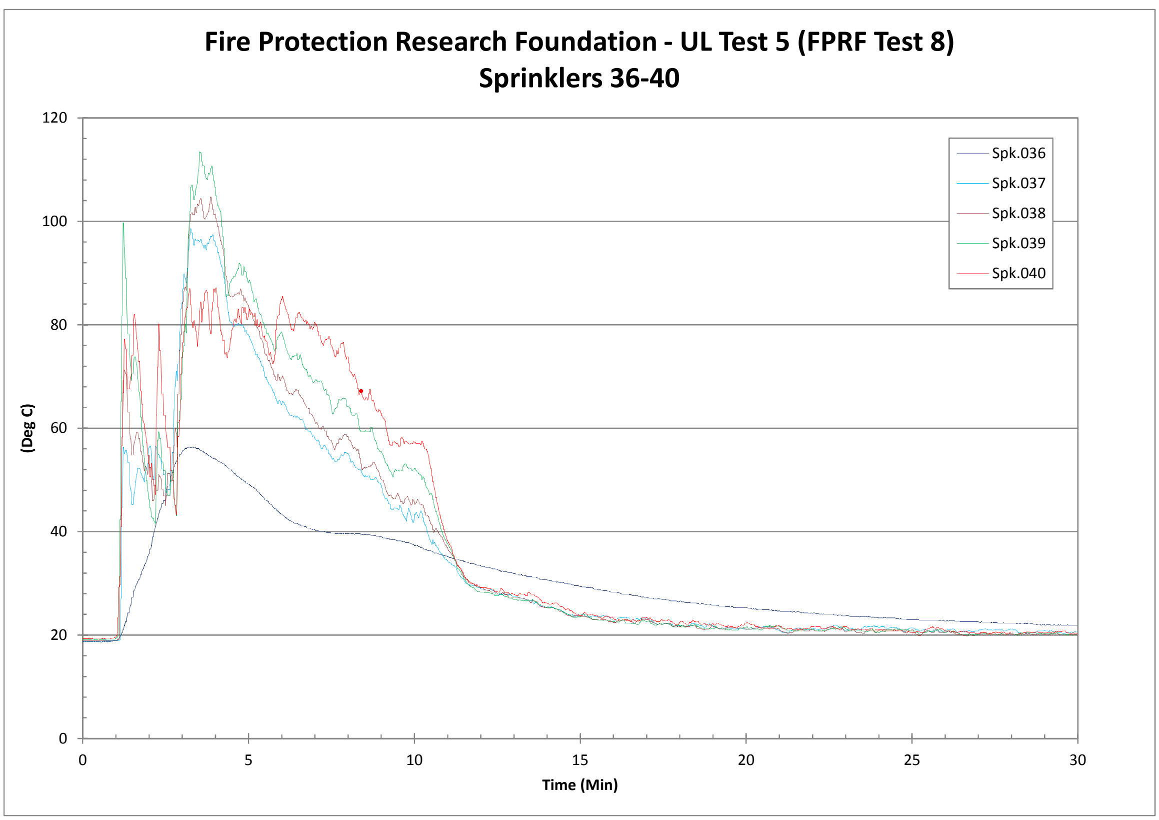

Fire Protection Research Foundation - UL Test 5 (FPRF Test 8)
Sprinklers 11-15
(Deg C)
Time (Min)
Spk.011
Spk.012
Spk.013
Spk.014
Spk.015
0
20
40
60
80
100
120
140
160
180
0
5
10
15
20
25
30

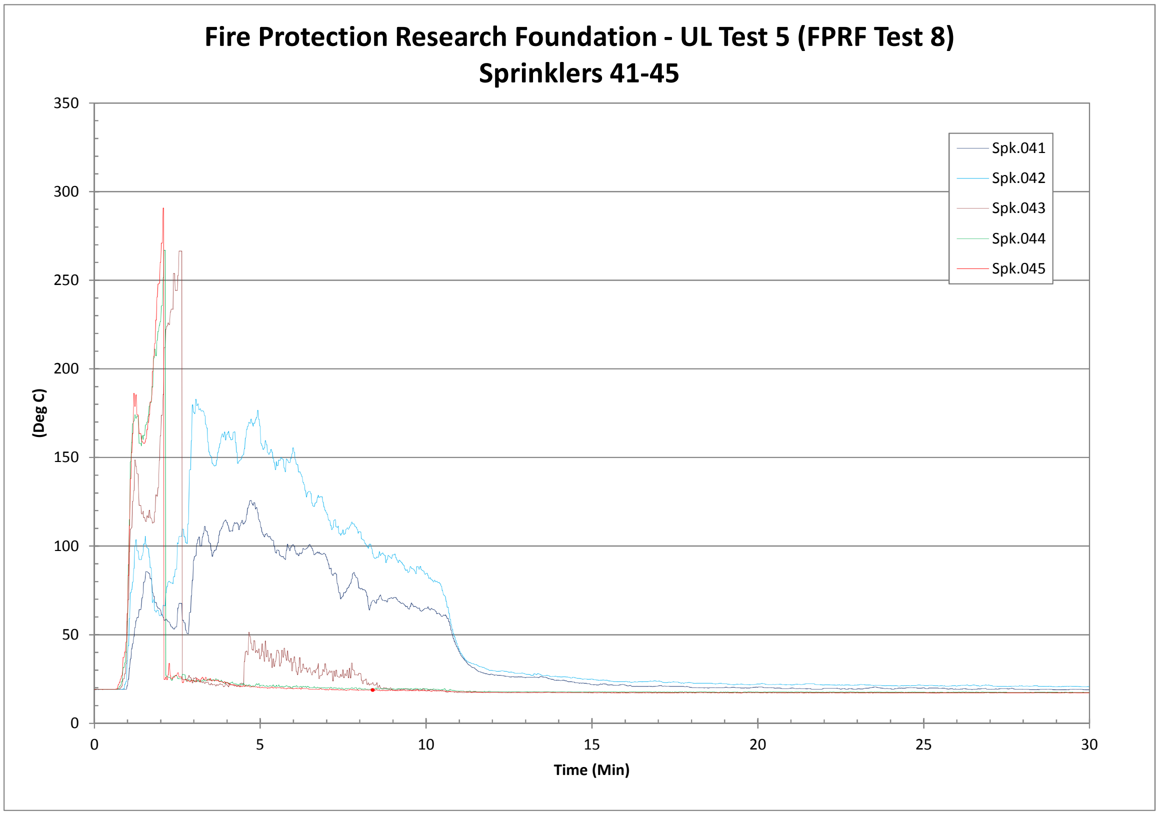

Fire Protection Research Foundation - UL Test 5 (FPRF Test 8)
Sprinklers 16-20
(Deg C)
Time (Min)
Spk.016
Spk.017
Spk.018
Spk.019
Spk.020
0
20
40
60
80
100
120
140
160
180
200
0
5
10
15
20
25
30

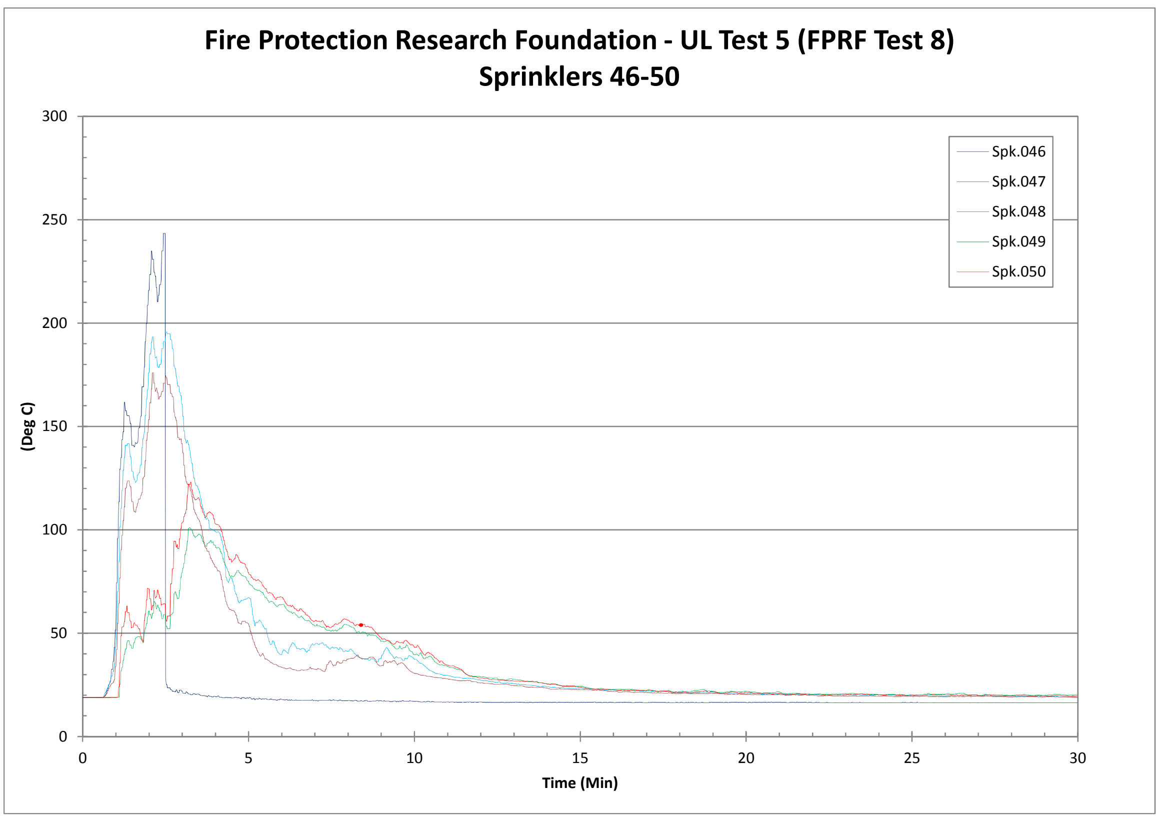

Fire Protection Research Foundation - UL Test 5 (FPRF Test 8)
Sprinklers 21-25
(Deg C)
Time (Min)
Spk.021
Spk.022
Spk.023
Spk.024
0
50
100
150
200
250
0
5
10
15
20
25
30

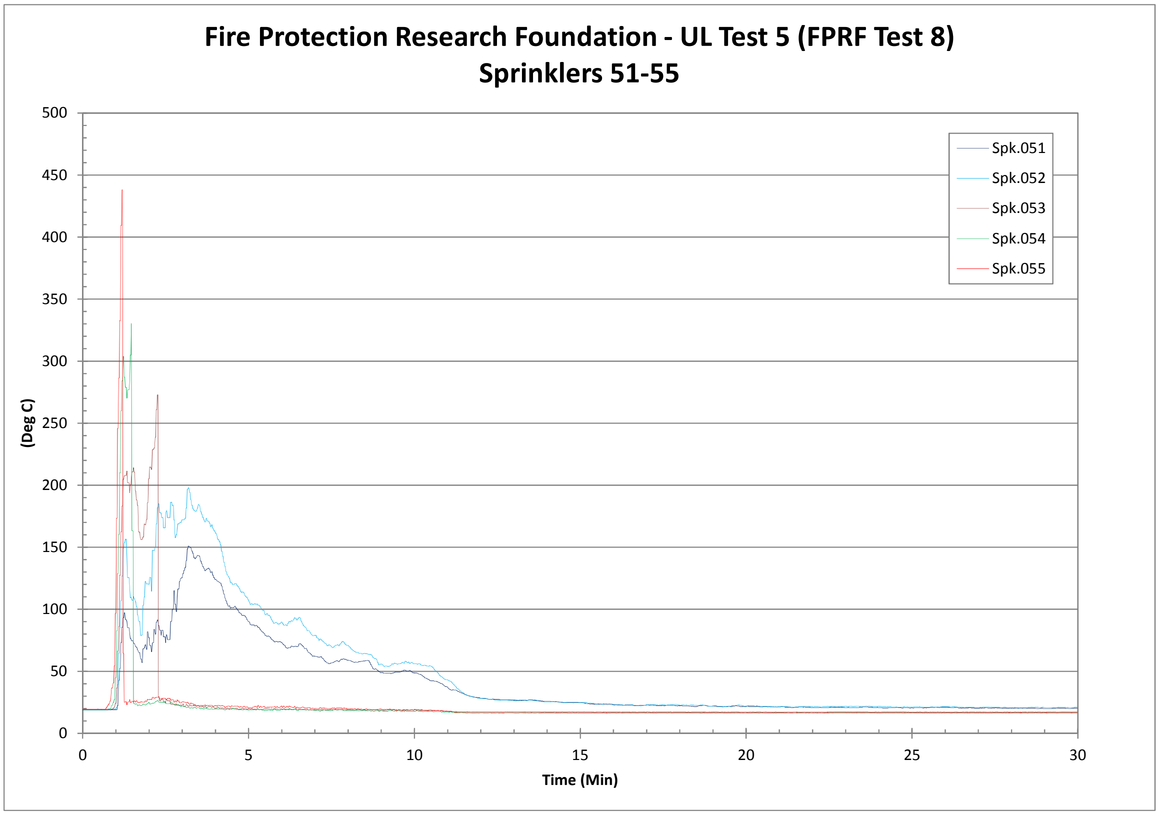

Fire Protection Research Foundation - UL Test 5 (FPRF Test 8)
Sprinklers 26-30
(Deg C)
Time (Min)
Spk.026
Spk.027
Spk.028
Spk.029
Spk.030
0
10
20
30
40
50
60
70
80
90
0
5
10
15
20
25
30

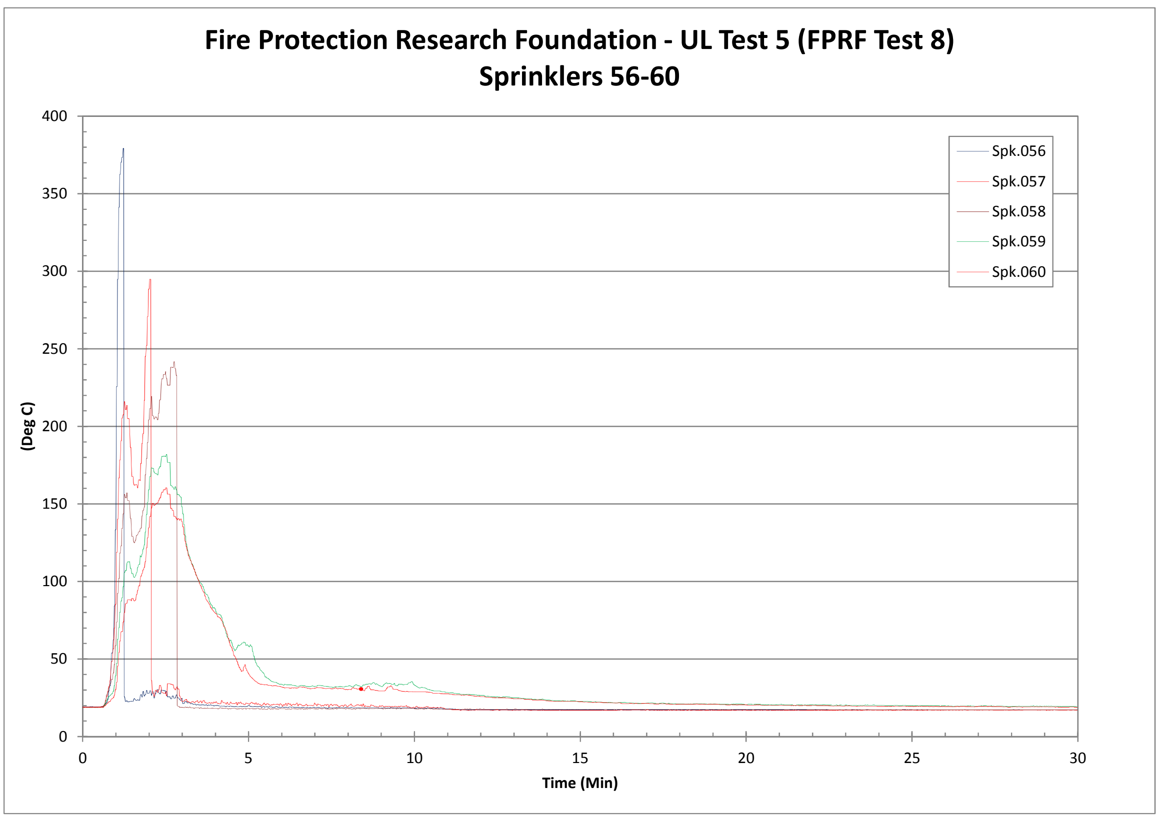

Fire Protection Research Foundation - UL Test 5 (FPRF Test 8)
Sprinklers 31-35
(Deg C)
Time (Min)
Spk.031
Spk.032
Spk.033
Spk.034
Spk.035
0
10
20
30
40
50
60
70
80
0
5
10
15
20
25
30

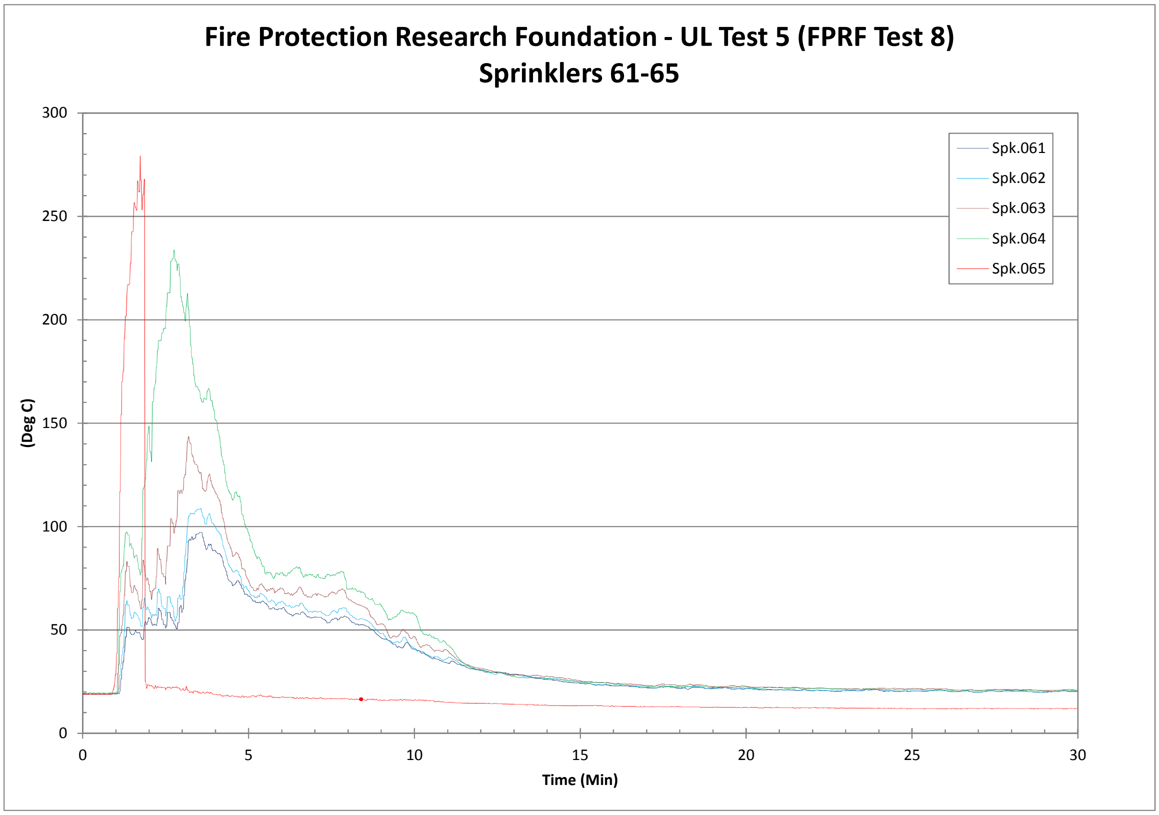

Fire Protection Research Foundation - UL Test 5 (FPRF Test 8)
Sprinklers 36-40
(Deg C)
Time (Min)
Spk.036
Spk.037
Spk.038
Spk.039
Spk.040
0
20
40
60
80
100
120
0
5
10
15
20
25
30

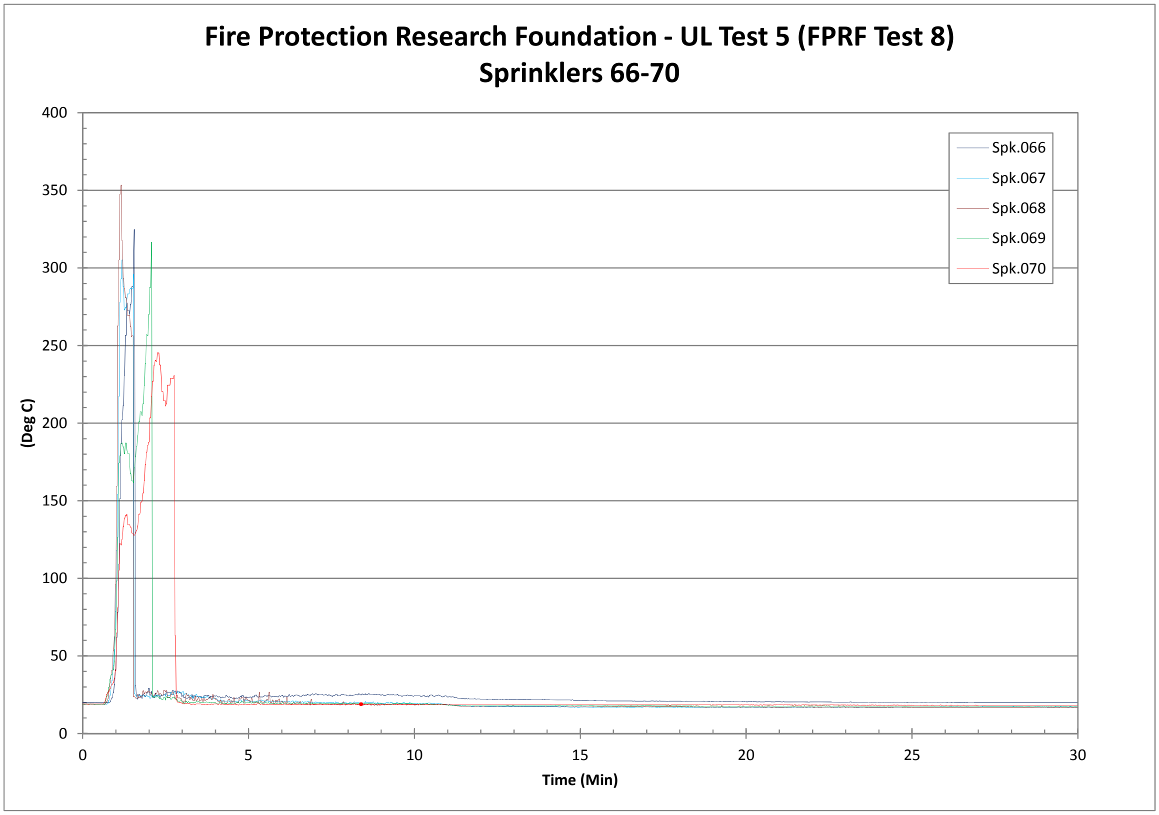

Fire Protection Research Foundation - UL Test 5 (FPRF Test 8)
Sprinklers 41-45
(Deg C)
Time (Min)
Spk.041
Spk.042
Spk.043
Spk.044
Spk.045
0
50
100
150
200
250
300
350
0
5
10
15
20
25
30

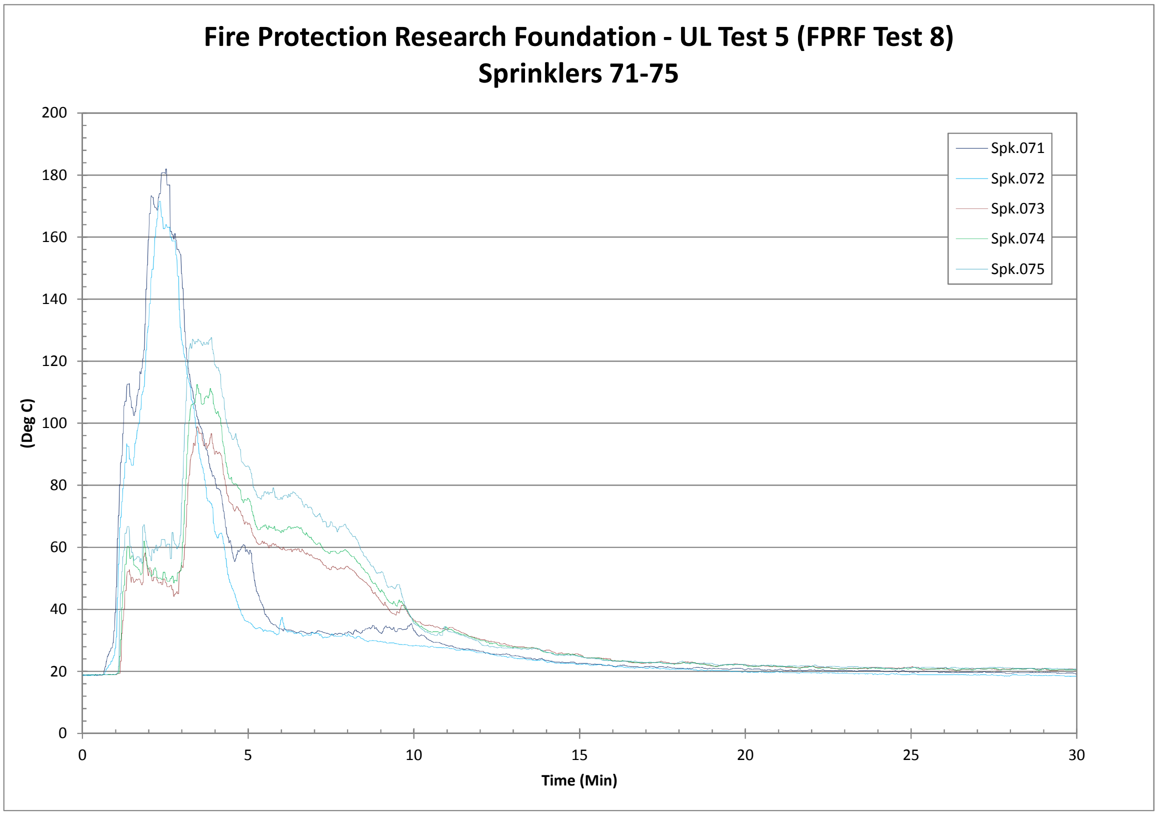

Fire Protection Research Foundation - UL Test 5 (FPRF Test 8)
Sprinklers 46-50
(Deg C)
Time (Min)
Spk.046
Spk.047
Spk.048
Spk.049
Spk.050
0
50
100
150
200
250
300
0
5
10
15
20
25
30

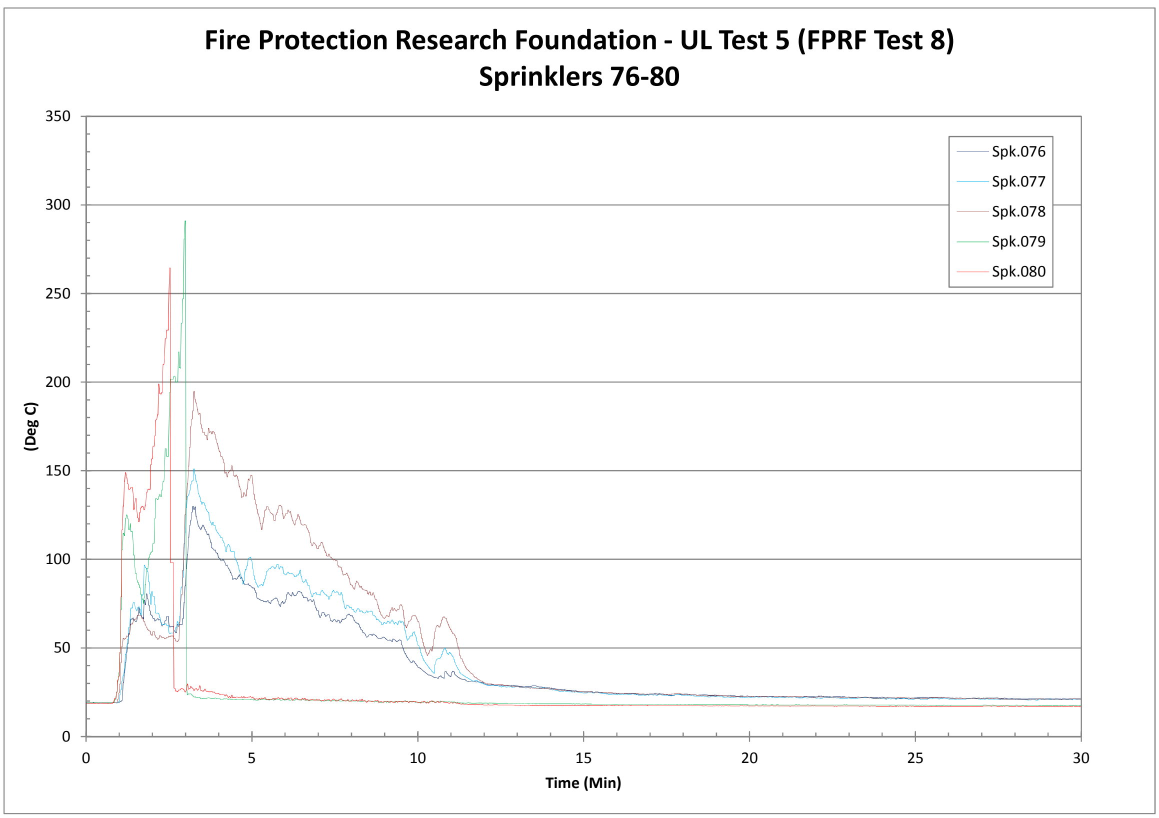

Fire Protection Research Foundation - UL Test 5 (FPRF Test 8)
Sprinklers 51-55
(Deg C)
Time (Min)
Spk.051
Spk.052
Spk.053
Spk.054
Spk.055
0
50
100
150
200
250
300
350
400
450
500
0
5
10
15
20
25
30

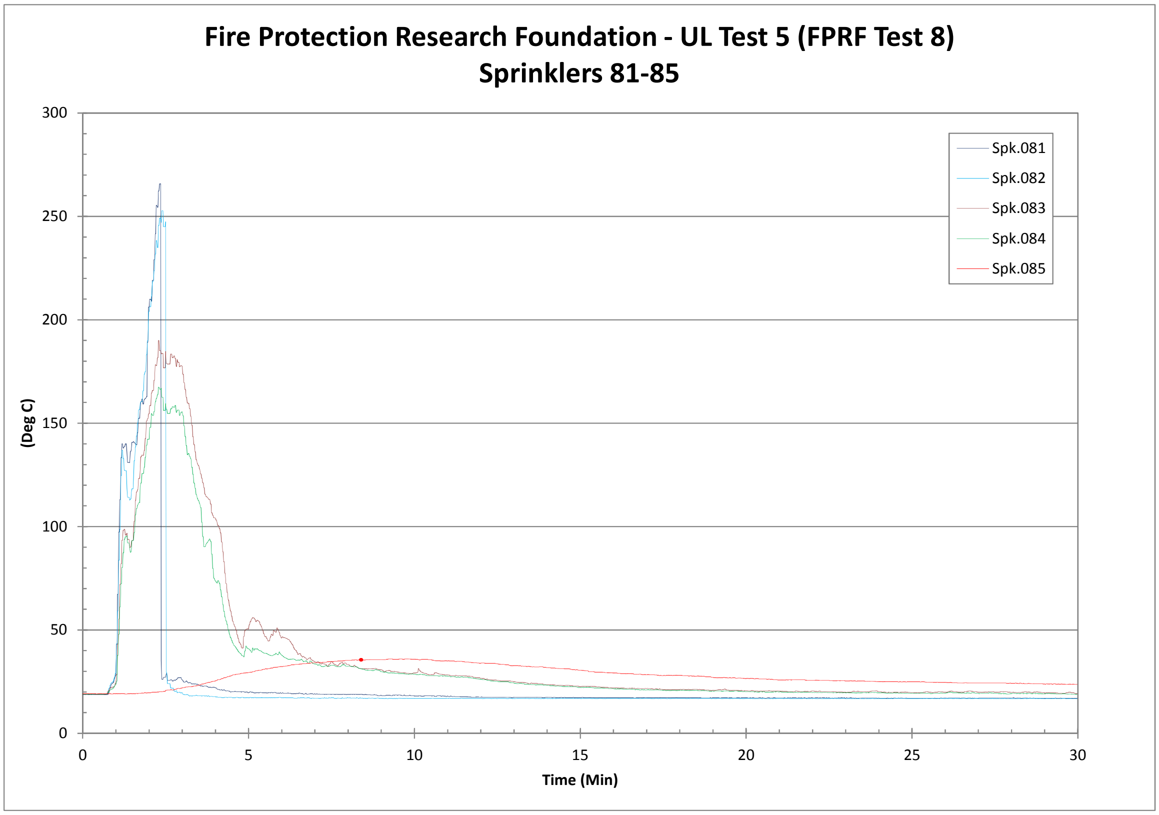

Fire Protection Research Foundation - UL Test 5 (FPRF Test 8)
Sprinklers 56-60
(Deg C)
Time (Min)
Spk.056
Spk.057
Spk.058
Spk.059
Spk.060
0
50
100
150
200
250
300
350
400
0
5
10
15
20
25
30

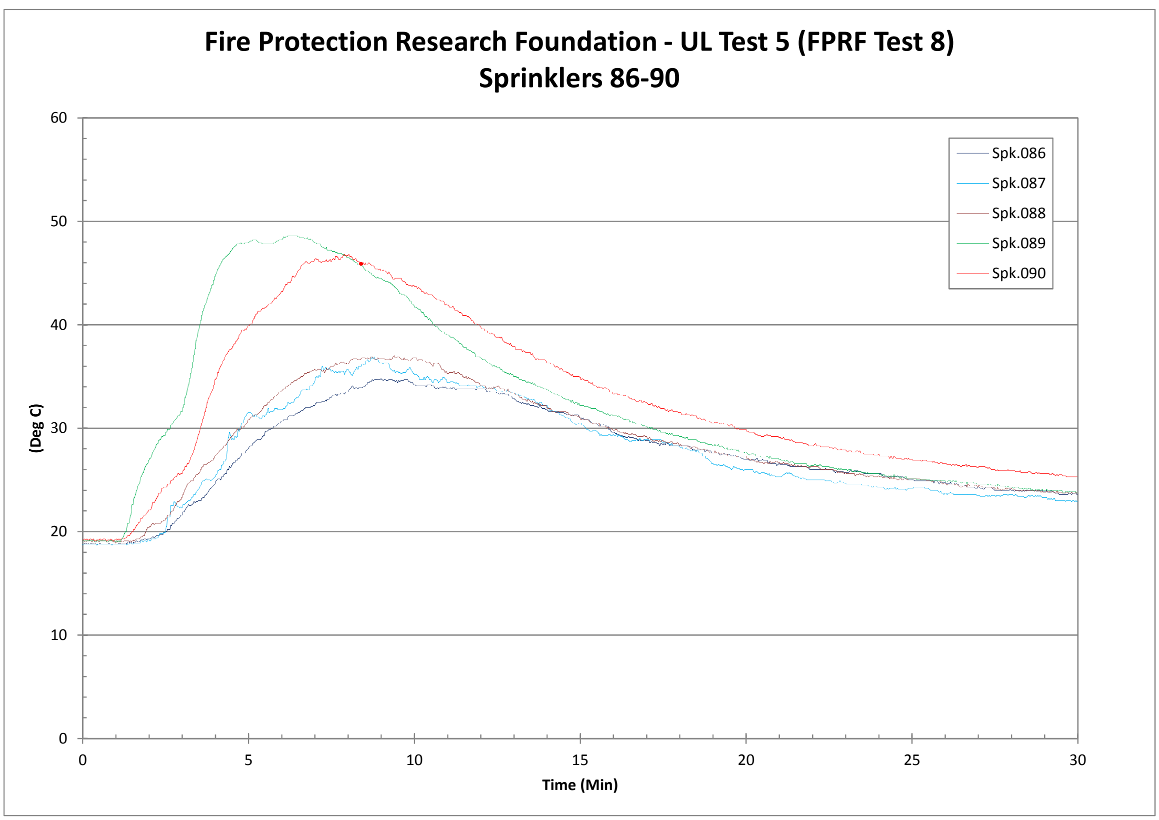

Fire Protection Research Foundation - UL Test 5 (FPRF Test 8)
Sprinklers 61-65
(Deg C)
Time (Min)
Spk.061
Spk.062
Spk.063
Spk.064
Spk.065
0
50
100
150
200
250
300
0
5
10
15
20
25
30

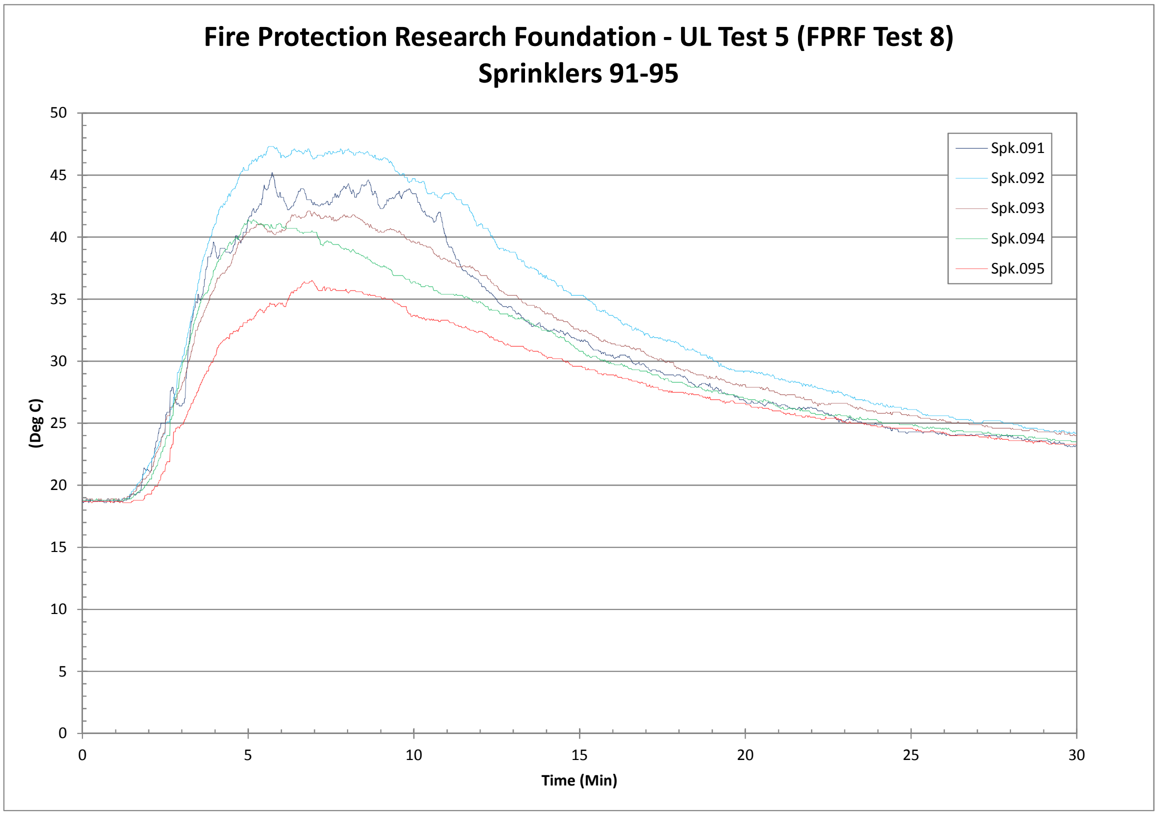

Fire Protection Research Foundation - UL Test 5 (FPRF Test 8)
Sprinklers 66-70
(Deg C)
Time (Min)
Spk.066
Spk.067
Spk.068
Spk.069
Spk.070
0
50
100
150
200
250
300
350
400
0
5
10
15
20
25
30

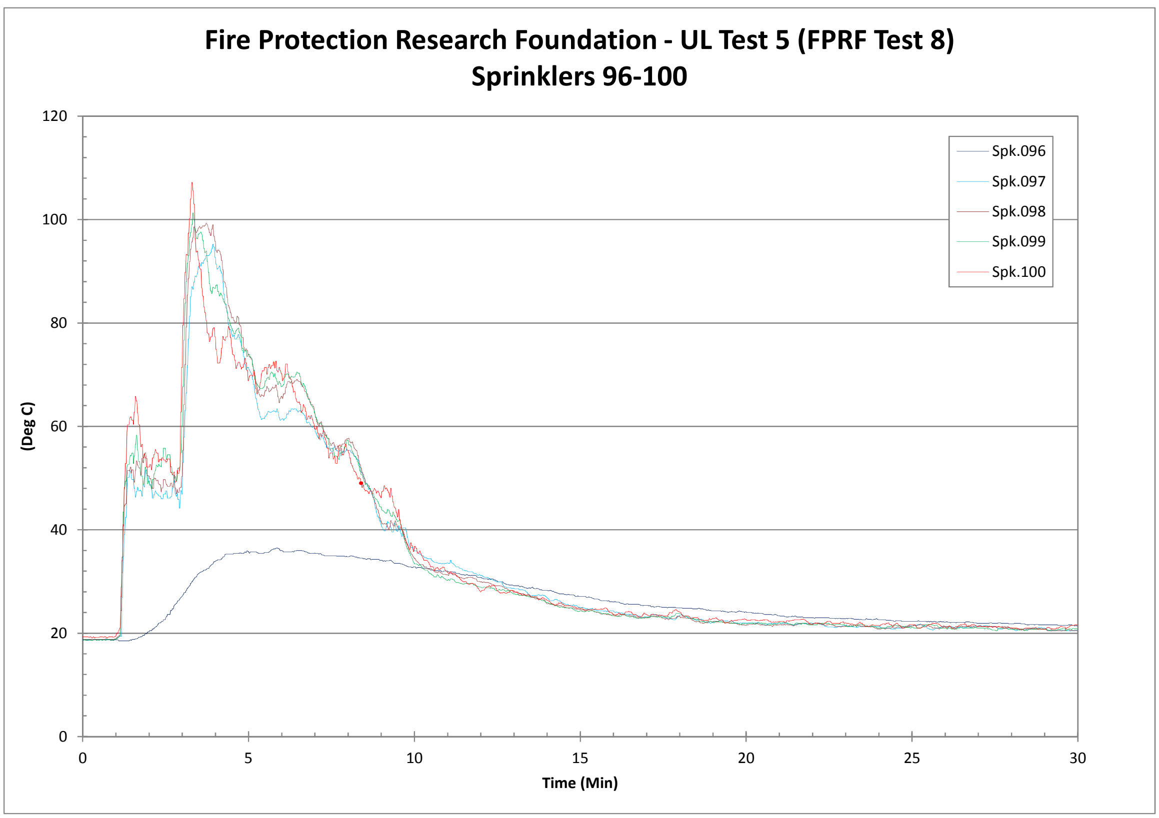

Fire Protection Research Foundation - UL Test 5 (FPRF Test 8)
Sprinklers 71-75
(Deg C)
Time (Min)
Spk.071
Spk.072
Spk.073
Spk.074
Spk.075

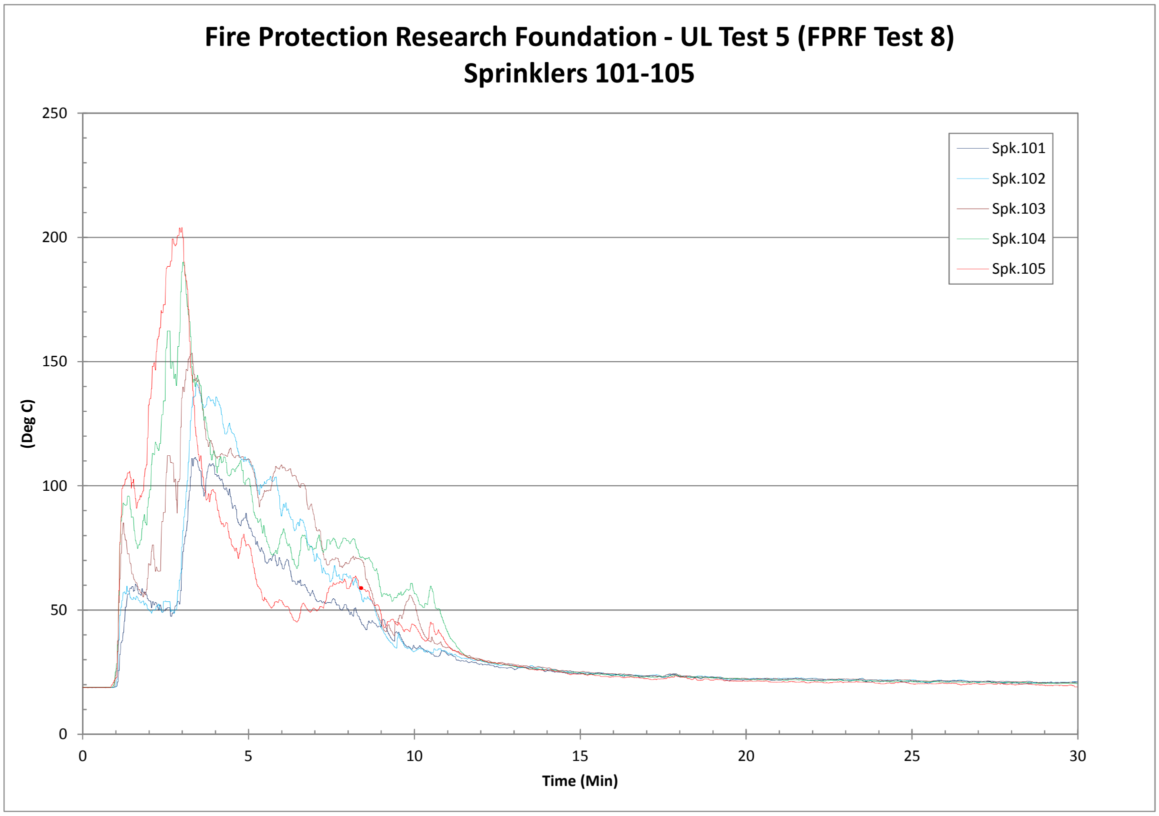

Fire Protection Research Foundation - UL Test 5 (FPRF Test 8)
Sprinklers 76-80
(Deg C)
Time (Min)
Spk.076
Spk.077
Spk.078
Spk.079
Spk.080

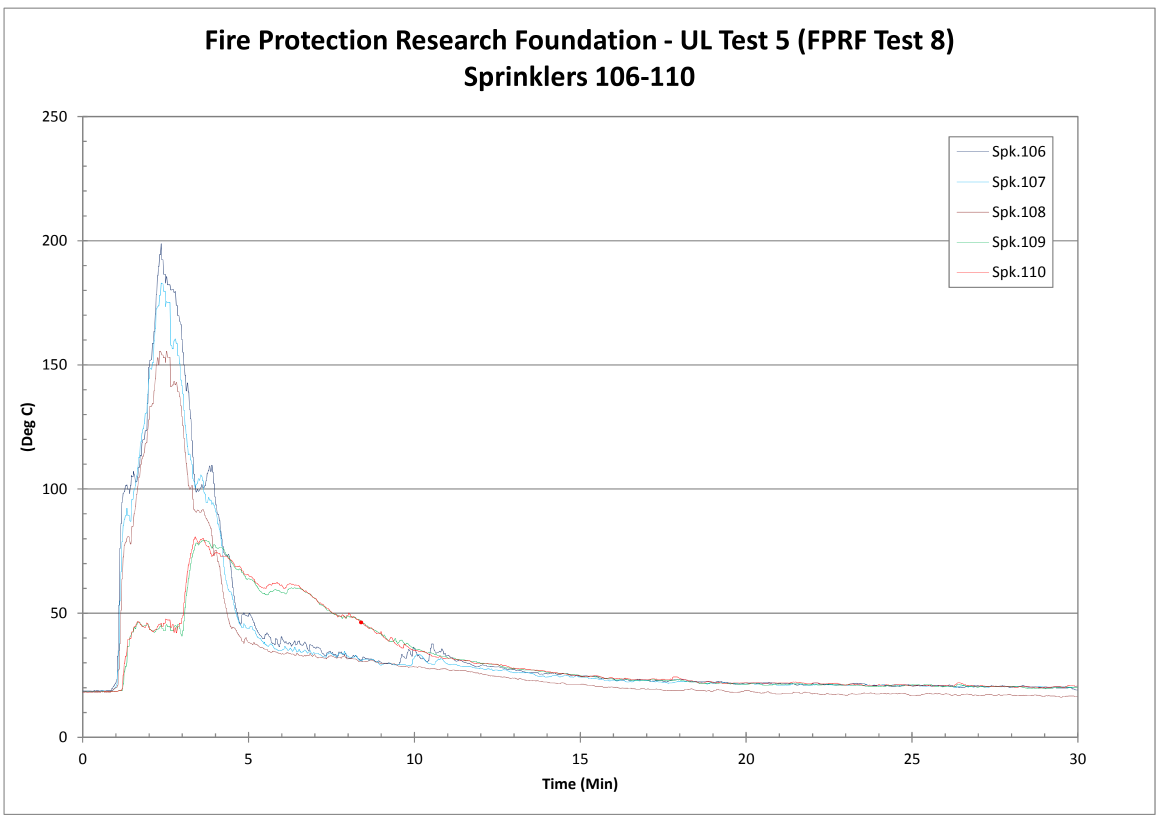

Fire Protection Research Foundation - UL Test 5 (FPRF Test 8)
Sprinklers 81-85
(Deg C)
Time (Min)
Spk.081
Spk.082
Spk.083
Spk.084
Spk.085
300
250
200
150
100
50
0
0
5
10
15
20
25
30

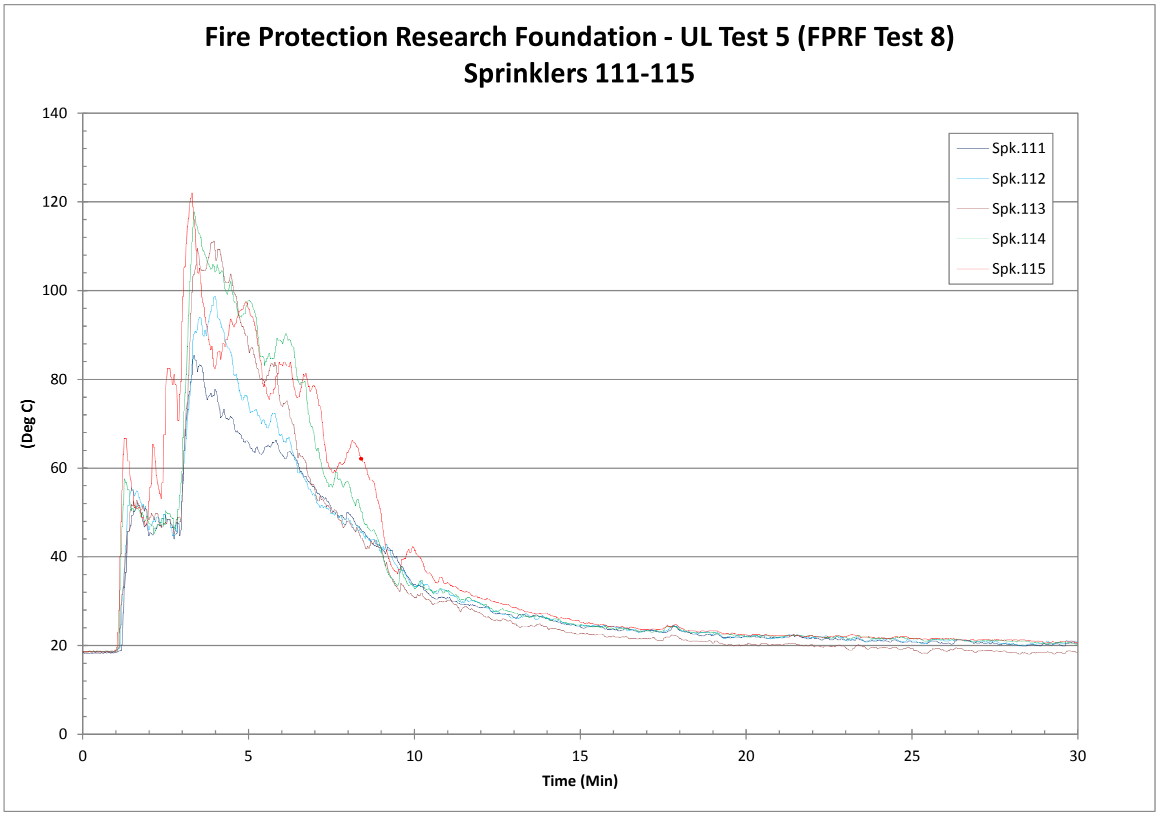

Fire Protection Research Foundation - UL Test 5 (FPRF Test 8)
Sprinklers 86-90
(Deg C)
Time (Min)
Spk.086
Spk.087
Spk.088
Spk.089
Spk.090
60
50
40
30
20
10
0
0
5
10
15
20
25
30

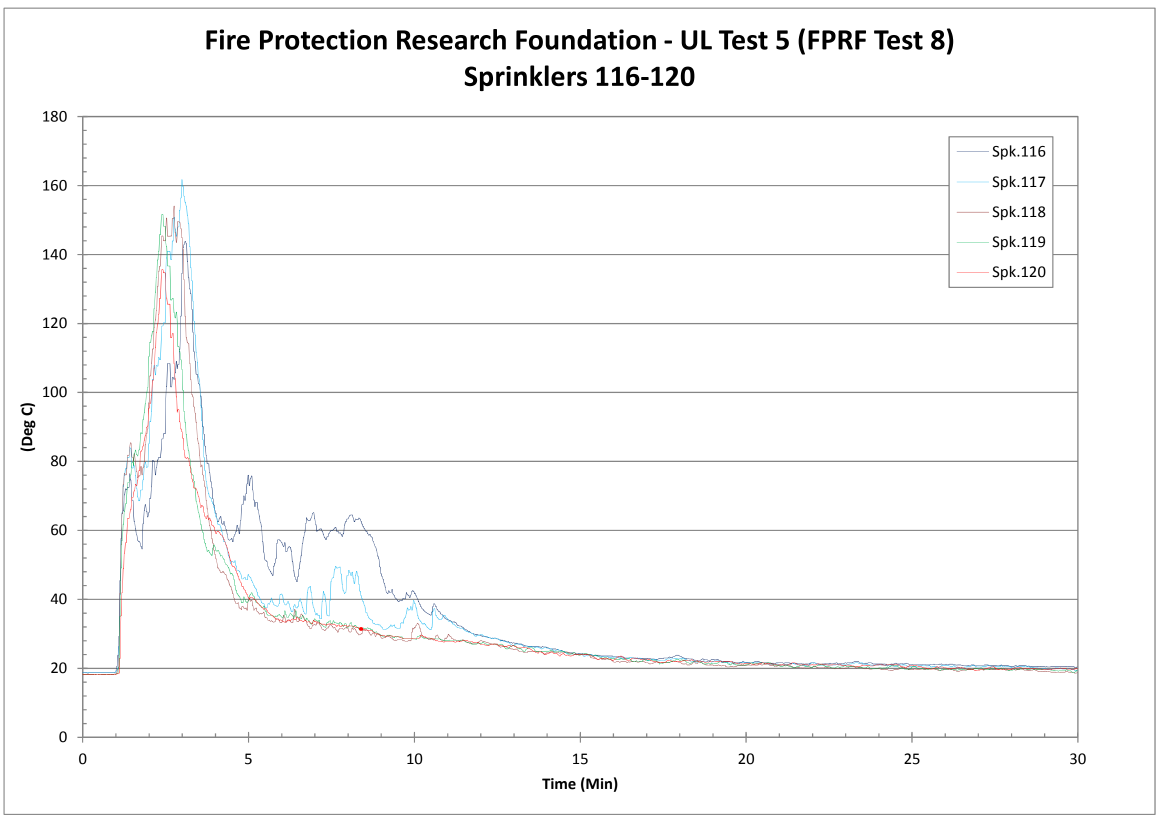

Fire Protection Research Foundation - UL Test 5 (FPRF Test 8)
Sprinklers 91-95
(Deg C)
Time (Min)
Spk.091
Spk.092
Spk.093
Spk.094
Spk.095

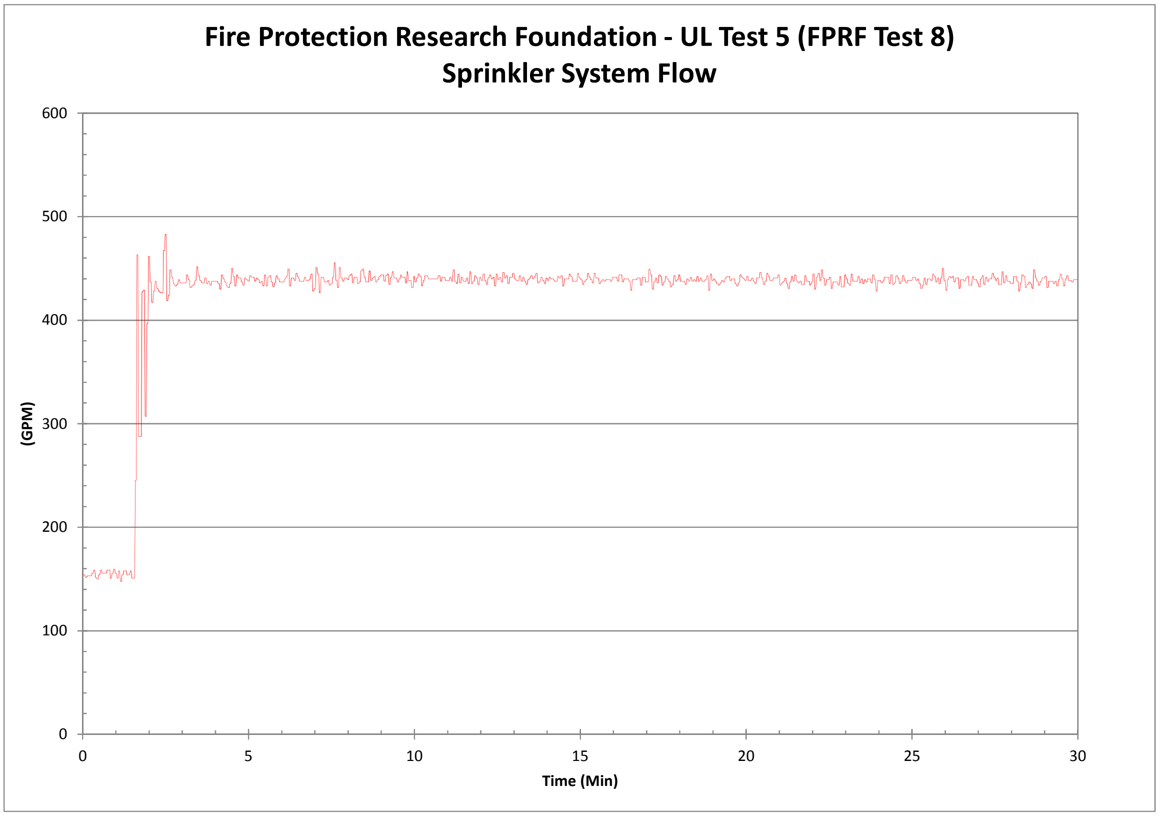

Fire Protection Research Foundation - UL Test 5 (FPRF Test 8)
Sprinklers 96-100
(Deg C)
Time (Min)
Spk.096
Spk.097
Spk.098
Spk.099
Spk.100

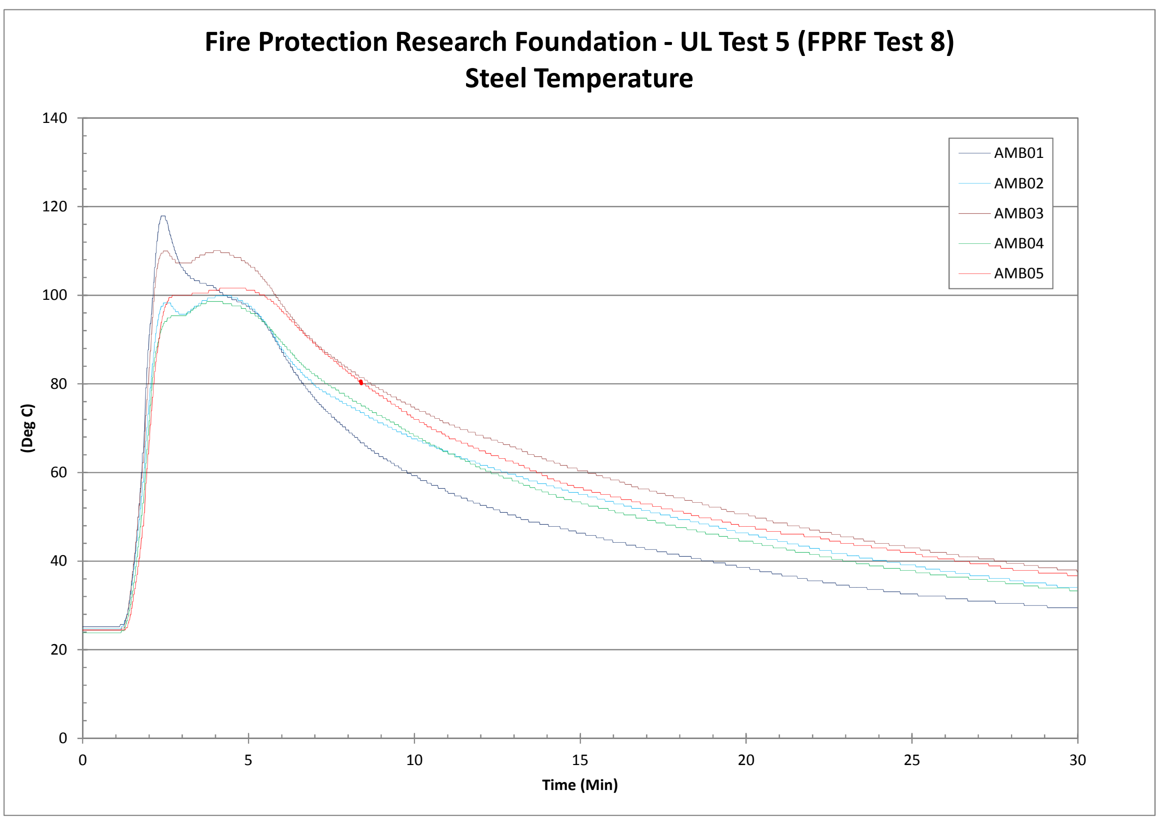

Fire Protection Research Foundation - UL Test 5 (FPRF Test 8)
Sprinklers 101-105
(Deg C)
Time (Min)
0
50
100
150
200
250
0
5
10
15
20
25
30
Spk.101
Spk.102
Spk.103
Spk.104
Spk.105

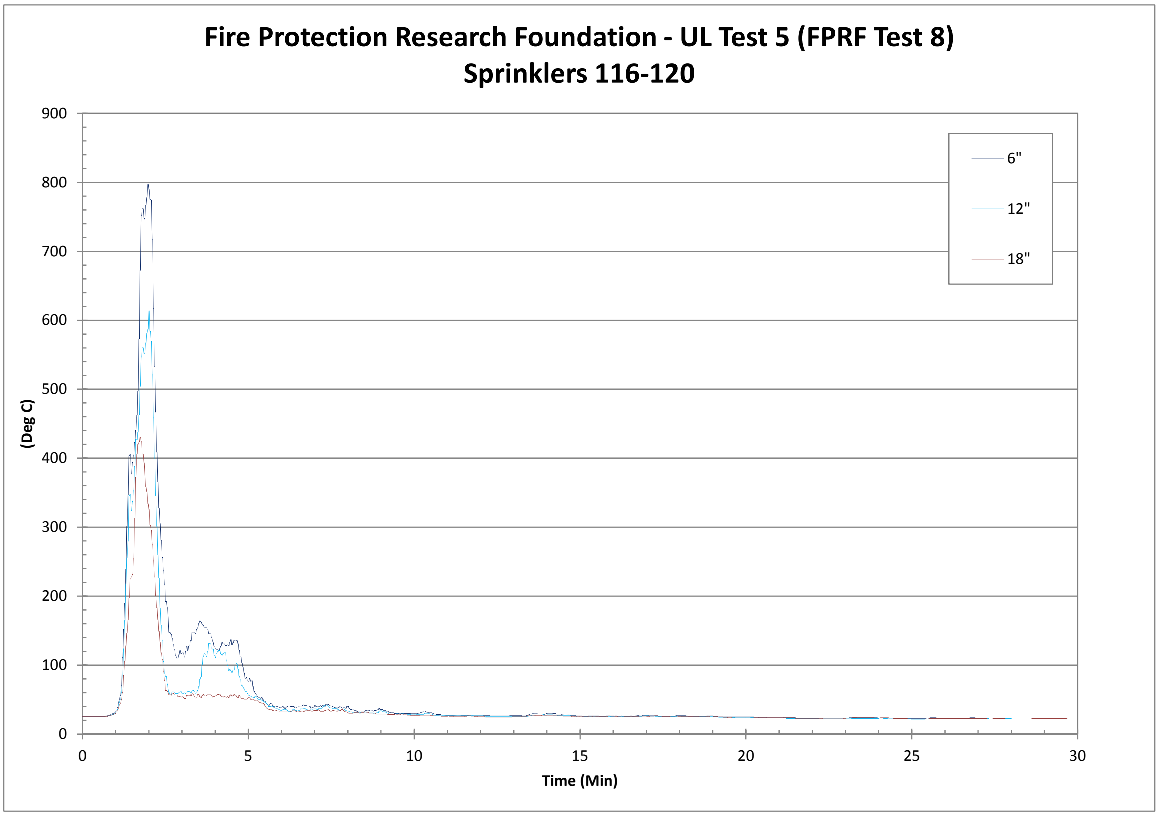

Fire Protection Research Foundation - UL Test 5 (FPRF Test 8)
Sprinklers 106-110
(Deg C)
Time (Min)
0
50
100
150
200
250
0
5
10
15
20
25
30
Spk.106
Spk.107
Spk.108
Spk.109
Spk.110

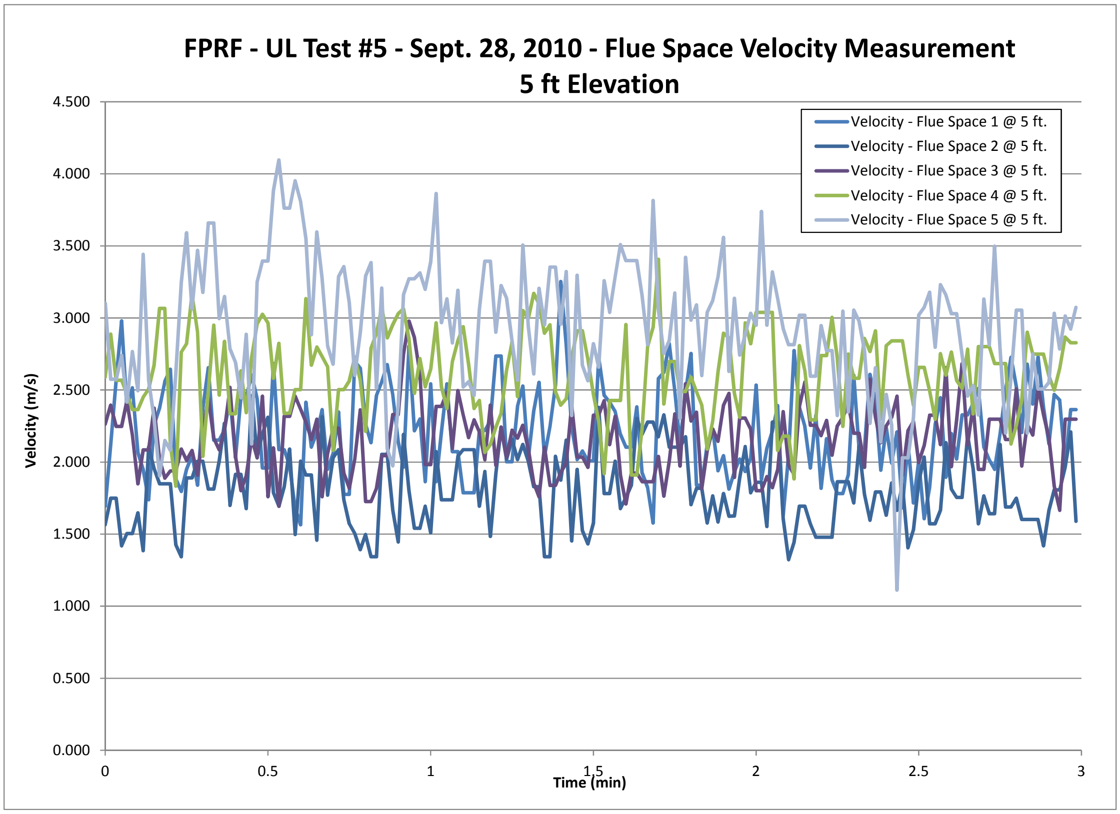

Fire Protection Research Foundation - UL Test 5 (FPRF Test 8)
Sprinklers 111-115
(Deg C)
Time (Min)
Spk.111
Spk.112
Spk.113
Spk.114
Spk.115
0
20
40
60
80
100
120
140
0
5
10
15
20
25
30

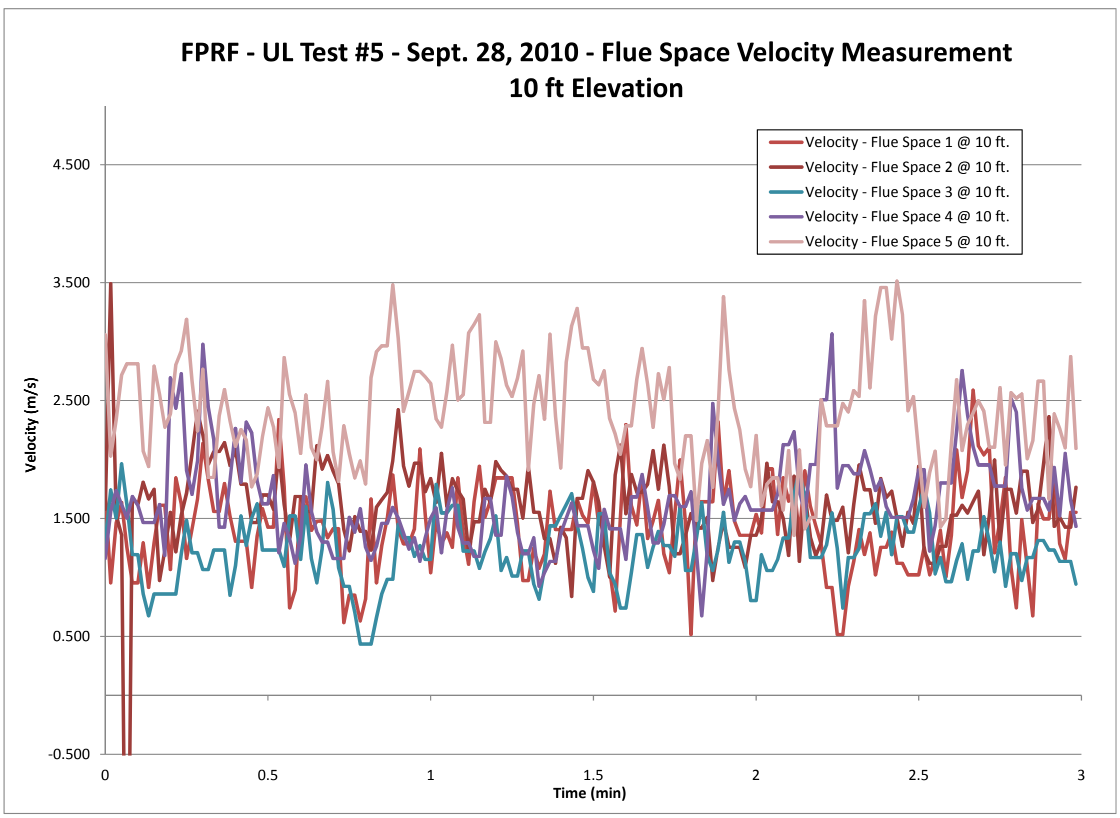

Fire Protection Research Foundation - UL Test 5 (FPRF Test 8)
Sprinklers 116-120
(Deg C)
Time (Min)
Spk.116
Spk.117
Spk.118
Spk.119
Spk.120
0
20
40
60
80
100
120
140
160
180
0
5
10
15
20
25
30

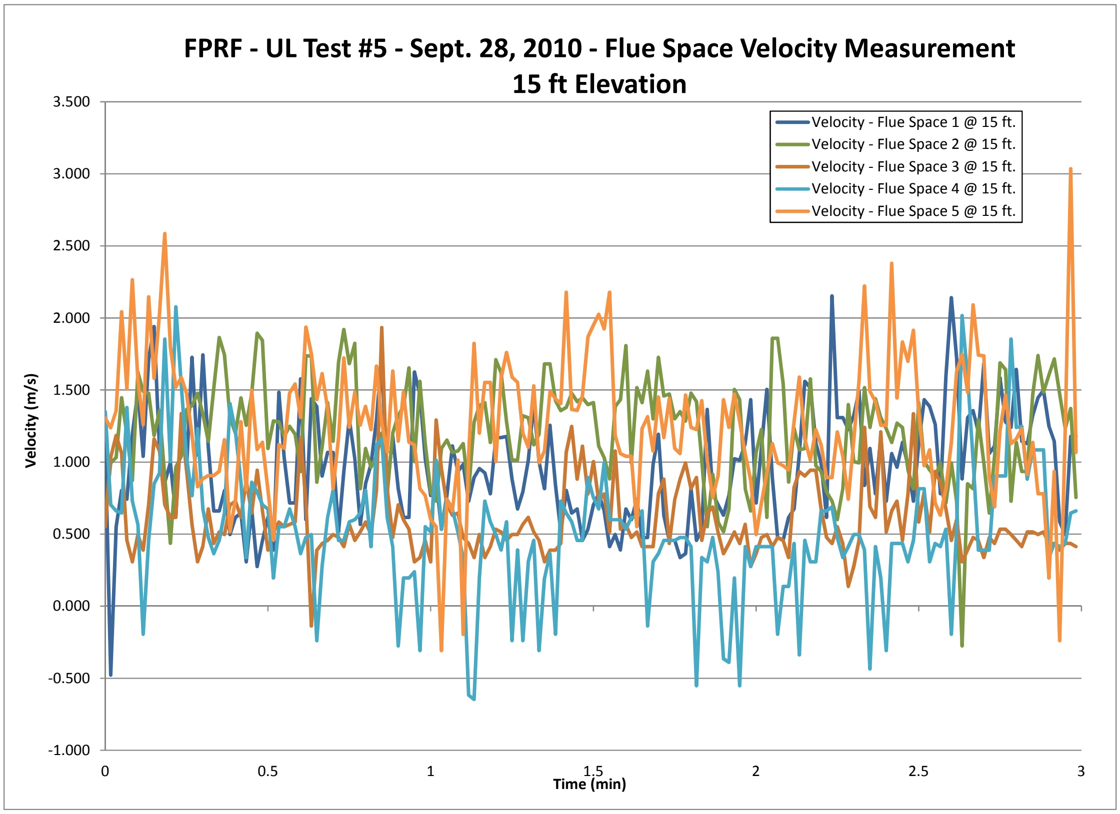

Fire Protection Research Foundation - UL Test 5 (FPRF Test 8)
Sprinkler System Flow
(GPM)
Time (Min)
0
100
200
300
400
500
600
0
5
10
15
20
25
30

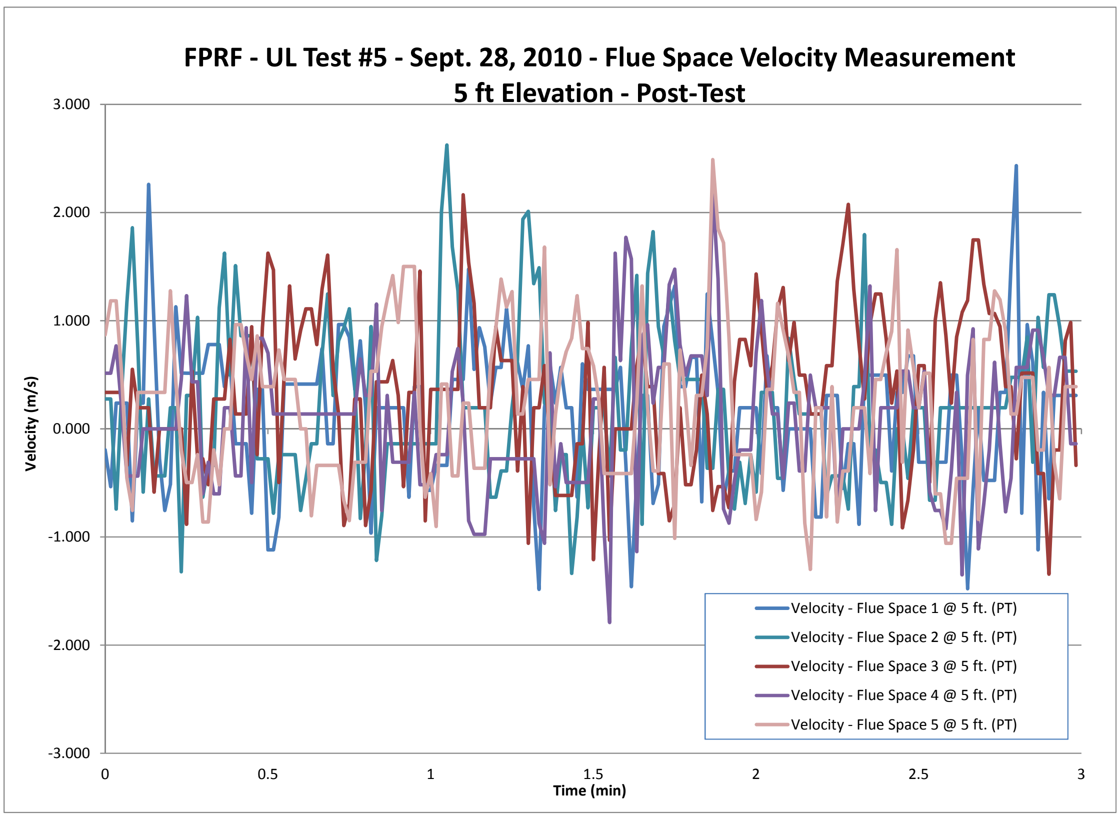

Fire Protection Research Foundation - UL Test 5 (FPRF Test 8)
Steel Temperature
(Deg C)
Time (Min)
AMB01
AMB02
AMB03
AMB04
AMB05
0
20
40
60
80
100
120
140
0
5
10
15
20
25
30

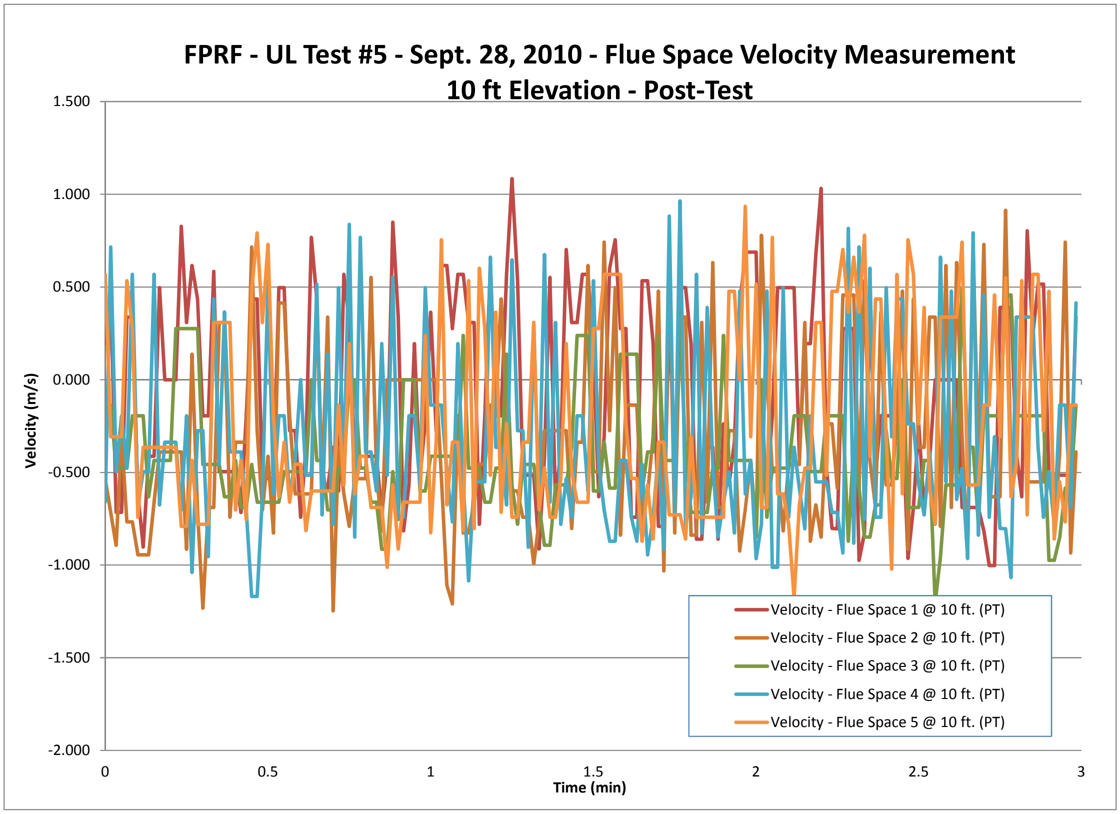

Fire Protection Research Foundation - UL Test 5 (FPRF Test 8)
Sprinklers 116-120
(Deg C)
0
100
200
300
400
500
600
700
800
900
Time (Min)
0
5
10
15
20
25
30
6"
12"
18"

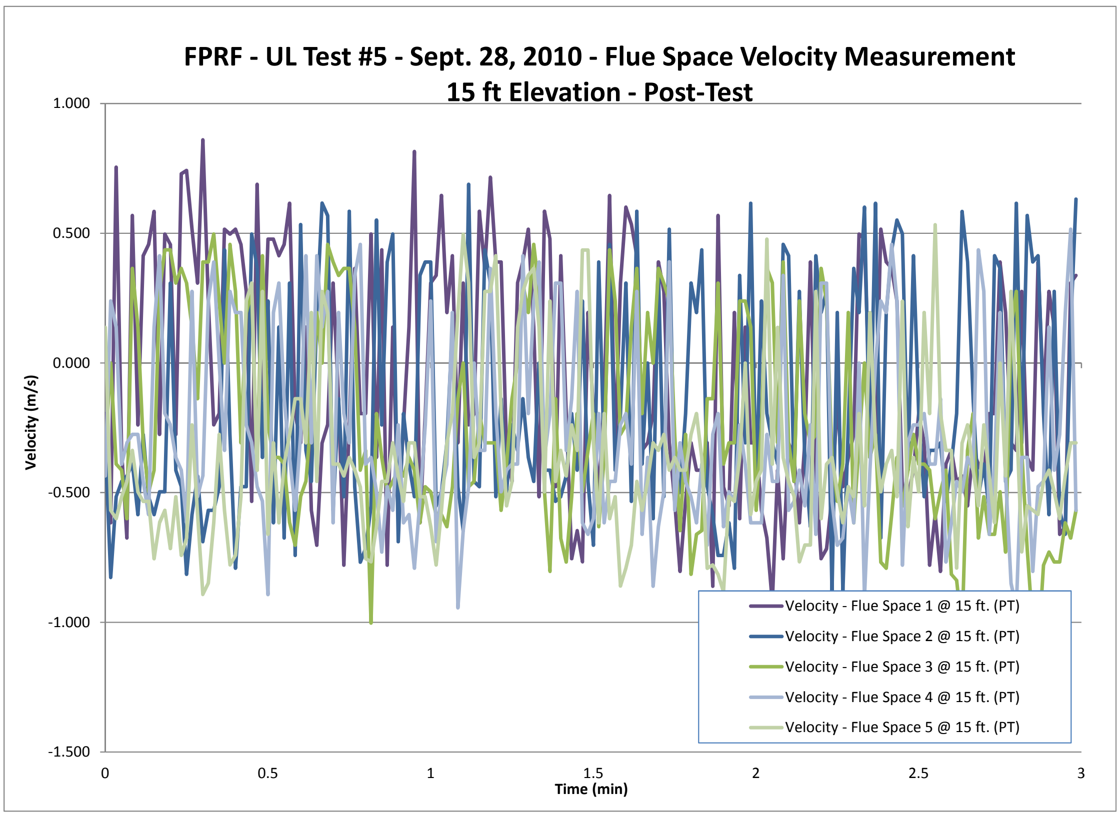

FPRF - UL Test #5 - Sept. 28, 2010 - Flue Space Velocity Measurement
5 ft Elevation
Velocity - Flue Space 1 @ 5 ft.
Velocity - Flue Space 2 @ 5 ft.
Velocity - Flue Space 3 @ 5 ft.
Velocity - Flue Space 4 @ 5 ft.
Velocity - Flue Space 5 @ 5 ft.
Velocity (m/s)
Time (min)
4.500
4.000
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
0
0.5
1
1.5
2
2.5
3


FPRF - UL Test #5 - Sept. 28, 2010 - Flue Space Velocity Measurement
10 ft Elevation
Velocity - Flue Space 1 @ 10 ft.
Velocity - Flue Space 2 @ 10 ft.
Velocity - Flue Space 3 @ 10 ft.
Velocity - Flue Space 4 @ 10 ft.
Velocity - Flue Space 5 @ 10 ft.
Velocity (m/s)
Time (min)
4.500
3.500
2.500
1.500
0.500
-0.500
0
0.5
1
1.5
2
2.5
3


FPRF - UL Test #5 - Sept. 28, 2010 - Flue Space Velocity Measurement
15 ft Elevation
Velocity (m/s)
Time (min)
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
-0.500
-1.000
0
0.5
1
1.5
2
2.5
3
Velocity - Flue Space 1 @ 15 ft.
Velocity - Flue Space 2 @ 15 ft.
Velocity - Flue Space 3 @ 15 ft.
Velocity - Flue Space 4 @ 15 ft.
Velocity - Flue Space 5 @ 15 ft.


FPRF - UL Test #5 - Sept. 28, 2010 - Flue Space Velocity Measurement
5 ft Elevation - Post-Test
Velocity (m/s)
Time (min)
3.000
2.000
1.000
0.000
-1.000
-2.000
-3.000
0
0.5
1
1.5
2
2.5
3
Velocity - Flue Space 1 @ 5 ft. (PT)
Velocity - Flue Space 2 @ 5 ft. (PT)
Velocity - Flue Space 3 @ 5 ft. (PT)
Velocity - Flue Space 4 @ 5 ft. (PT)
Velocity - Flue Space 5 @ 5 ft. (PT)


FPRF - UL Test #5 - Sept. 28, 2010 - Flue Space Velocity Measurement
10 ft Elevation - Post-Test
Velocity (m/s)
1.500
1.000
0.500
0.000
-0.500
-1.000
-1.500
-2.000
0
0.5
1
1.5
2
2.5
3
Time (min)
Velocity - Flue Space 1 @ 10 ft. (PT)
Velocity - Flue Space 2 @ 10 ft. (PT)
Velocity - Flue Space 3 @ 10 ft. (PT)
Velocity - Flue Space 4 @ 10 ft. (PT)
Velocity - Flue Space 5 @ 10 ft. (PT)


FPRF - UL Test #5 - Sept. 28, 2010 - Flue Space Velocity Measurement
15 ft Elevation - Post-Test
Velocity (m/s)
1.000
0.500
0.000
-0.500
-1.000
-1.500
0
0.5
1
1.5
2
2.5
3
Time (min)
Velocity - Flue Space 1 @ 15 ft. (PT)
Velocity - Flue Space 2 @ 15 ft. (PT)
Velocity - Flue Space 3 @ 15 ft. (PT)
Velocity - Flue Space 4 @ 15 ft. (PT)
Velocity - Flue Space 5 @ 15 ft. (PT)

Fire Protection Engineering

APPENDIX E – 11/12/2010 XL GAPS TEST REPORT EXCERPTS

11/12/2010 XL GAPS TEST REPORT EXCERPTS

The following figures are from the 11/12/2010 XL GAPS Test (UL-6) research report. The full report has not been released at this time.

XL GAPS (UL Test 6)

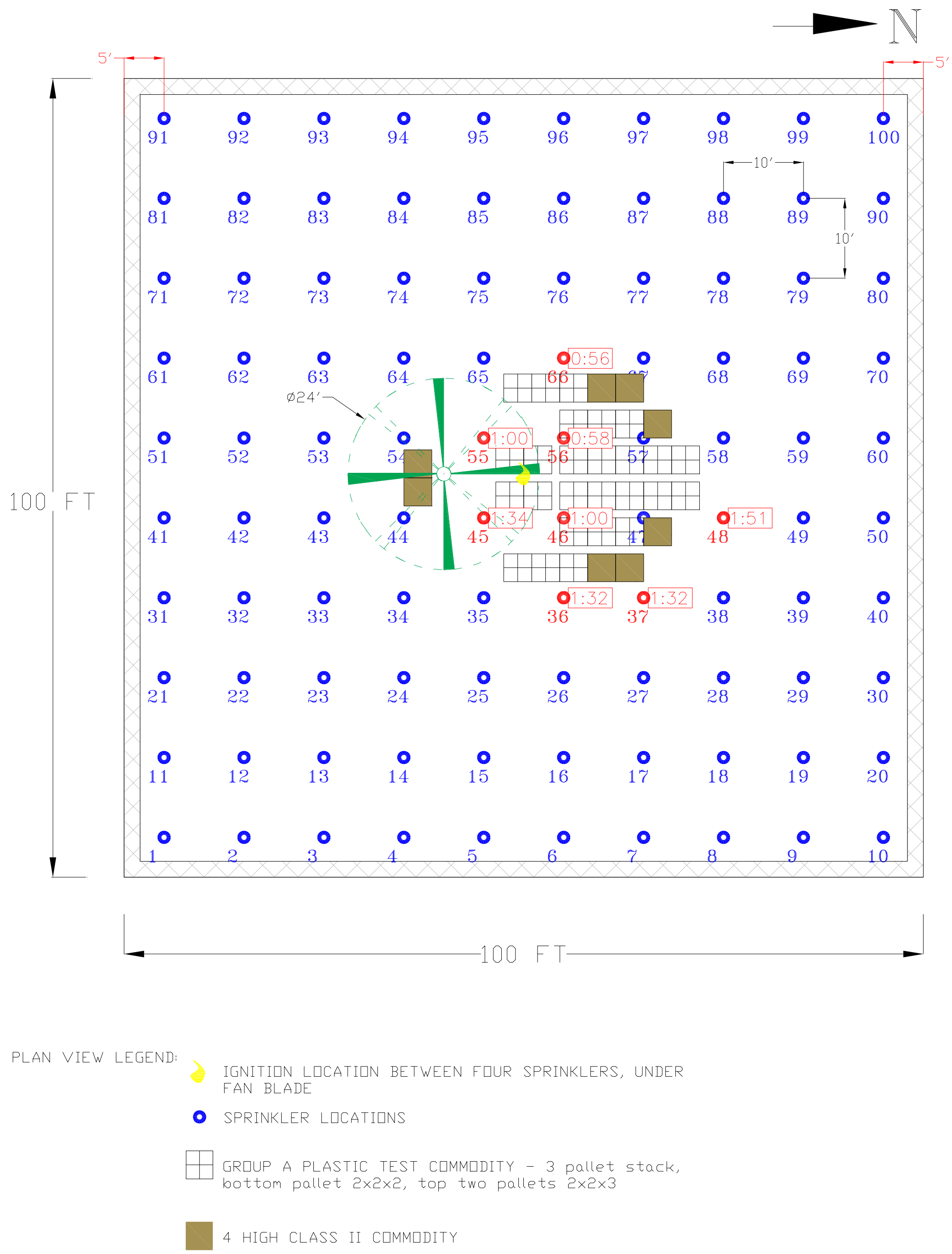


Table 1: Results from XL GAPS Fire Test Dated 11/12/2010

FIRE TEST	11/12/2010
PARAMETERS	
Location of Test	U.L.
Storage Type	Palletized Open Array
Commodity Type	Cartoned, Unexpanded Group A Plastic
Nominal Storage Height (ft)	15
Nominal Ceiling Height (ft)	40
Nominal Clearance (ft)	25
Aisle Width (in.)	N/A
Longitudinal/Transverse Flue (in.)	12
Ignition Location	Between 4 Sprinklers (centered)
Igniter Details	2 Full Igniters - 3" by 6" Each with 8 oz Gasoline
Sprinkler Type/Temperature Rating (°F)	ESFR/165
Sprinkler Orientation	Pendent
Sprinkler Sensitivity	Fast Response
Sprinkler Make/Model Number	Tyco/ESFR-1
Deflector to Ceiling (in.)	14
Nominal Sprinkler Discharge Coefficient K (gpm/psi^{½})	14
Density/Nominal Sprinkler Discharge Pressure (psi)	75
Sprinkler Spacing (ft x ft)	10 x 10
Fan Size (ft)	24
Fan Location	Fan Tip 2 ft Beyond Ignition
Fan Distance Below Ceiling (in.)	72
HVLS Fan Speed (rpm)	64
HVLS Fan Operation	On (no shutdown)
HVLS Fan Manufacturer	Rite-Hite
HVLS Fan Model Name	Revolution
HVLS Fan Blade Geometry	Propell-Aire Standard
HVLS Fan Number of Blades	4
RESULTS	
Length of Test (hr:min:s)	0:30:00
First Ceiling Sprinkler Operation (min:s)	0:56
Last Ceiling Sprinkler Operation (min:s)	1:51
Number of Operated Ceiling Sprinklers	8
Peak Gas Temperature at Ceiling Above Ignition (°F)	181
Max. 1 Min. Average Gas Temp. at Ceiling Above Ignition (°F)	131
Peak Steel Temperature at Ceiling Above Ignition (°F)	121
Max. 1 Min. Average Steel Temp. Above Ignition (°F)	116
Fire Spread Across Aisle	NO
Fire spread to the Ends of the Array	NO
Fuel Consumed (number of pallets)	28
Test Outcome (Pass/Fail)	PASS
Comments	Repeat of Test 4 using different fan model