RESEARCH AND DEVELOPMENT TECHNICAL REPORT

Comparative fire performance tests using water and antifreeze solutions discharged from standard spray sprinklers

Empowering Trust®

Sept. 16, 2020

Executive summary

A series of fire tests were conducted in UL's fire test facilities located in Northbrook, Illinois to determine the effectiveness of sprinklers discharging water compared to certain antifreeze solutions currently referenced in the Standard for Inspection, Testing and Maintenance of Water-Based Fire Protection Systems, NFPA 25[1]. The primary focus of this research initiative was to develop comparative test data related to fires that may originate in a light hazard occupancy; however, comparative data was also developed using an existing fire test protocol utilized for sprinklers intended for use in the Standard for the Installation on Sprinkler Systems, NFPA 13 [2] that relates to an ordinary hazard occupancy. Lastly, additional exposure to fire tests beyond those described in previous antifreeze research initiatives were conducted on antifreeze solutions currently referenced in NFPA 25 and are included in this report.

In order to compare fire test performance related to a light hazard occupancy, a fuel package was developed that (1) had fire size characteristics similar to an office workstation type fire and (2) could be controlled with sprinklers discharging water at a density of 0.10 gpm/ft^2, which is the density that is referenced in NFPA 13 for light hazard occupancy protection.

The sprinkler system consisted of a total of 36 upright standard spray sprinklers having a nominal discharge coefficient of 5.6 gpm/psi^{½} installed on a 14-foot-by-14-foot spacing with the deflectors located approximately 3 inches. below the ceiling. The sprinkler piping was arranged in a "tree" branch line configuration with sufficient supply and branch line piping to accommodate a total volume of approximately 500 gallons of antifreeze solution. A total of six tests were conducted using the light hazard fuel package located between two sprinklers on separate branch lines.

Three tests were conducted using a nominal sprinkler discharge density of 0.10 gpm/ft^2 for the duration of the test, which correlated to a discharge pressure of 12.3 psig for water. One test was conducted using water as a wet system, one test was conducted using water as a simulated dry system, and one test was conducted with 500 gallons of a 50% (by volume) glycerin antifreeze solution followed by water. During the test using water in a wet system, a total of four sprinklers operated compared to 12 sprinklers that operated during the test using the glycerin solution followed by water. During the simulated dry system testing with water, a total of 10 sprinklers operated.

Three tests were conducted using a higher sprinkler discharge pressure, based on a nominal 24 psig discharge pressure for water, to simulate a higher starting pressure for a sprinkler system that was hydraulically designed for a 0.10 gpm/ft^2 discharge density. One test was conducted with water, one test was conducted with approximately 500 gallons of a 50 percent glycerin antifreeze solution followed by water, and one test was conducted with 500 gallons of a 38 percent glycerin antifreeze solution followed by water. During the test using water, a total of two sprinklers operated compared to seven sprinklers that

operated during the test using the 50 percent glycerin and 5 sprinklers that operated during the test using the 38 percent glycerin solution.

For sprinkler systems protecting an ordinary hazard occupancy using an antifreeze solution volume greater than 40 gallons, UL 290, the Standard for Antifreeze Solutions for use in Fire Sprinkler Systems[3], requires fire testing using a fuel package described in the Standard for Automatic Sprinklers, UL 199 [4]. This fire test is used by UL to certify most standard spray sprinklers. For this testing, four open sprinklers were arranged to discharge either water only or antifreeze solutions followed by water onto the fire. The nominal sprinkler discharge density used for this UL 199 fire test is 0.15 gpm/ft^2 and the sprinklers are required to control the fire such that the ceiling temperature above the fire is generally maintained below a nominal 600 degrees Fahrenheit after 5 minutes of water discharge. Three tests were conducted: one using water, one using 38 percent glycerin antifreeze solution followed by water and one test using a 30 percent propylene glycol antifreeze solution followed by water. During the three tests, the ceiling temperature was reduced to below 600 °F after 5 minutes of water discharge compared to approximately 1,450 degrees Fahrenheit for the glycerin solution and 1350°F for the propylene glycol solution prior to being followed with water. At the time of publication of this report, there were no antifreeze solutions that are UL Listed for ordinary hazard occupancy applications with system volumes greater than 40 gallons.

For all tests with the antifreeze solutions, the test pressure was adjusted due to the difference in density between antifreeze and water to maintain the required flow rate and discharge density.

A description of the test parameters and results for the light hazard type tests is provided in Table 1 (English units) and Table 2 (Metric units). A graphical presentation of the ceiling temperatures for the ordinary hazard type fire tests are described in Figure 24.

Currently, UL 2901 describes three types of fire tests as follows:

- Exposure to Fire (evaluates the antifreeze solution for resistance to ignition and substantial contribution to the fire)
- Fire Fighting Effectiveness -- Residential Dwelling Units
- Fire Fighting Effectiveness -- Ordinary Hazard Occupancies, UL 199 - 350pounds Wood Crib Fire Test for sprinkler systems with volumes greater than 40 gallons.

Tables 3-5 (Imperial units) and Tables 6-8 (Metric units) provide information on the results of the fire testing that has been conducted on the legacy NFPA 13 glycerin and propylene glycol antifreeze solutions using the three UL 2901 fire tests and the light hazard fire test described herein as compared the acceptance criteria that is required for UL Listing.

Table 1: Light Hazard Occupancy Fire Test Summary Table

FIRE TEST REFERENCE	No. 1	No. 2	No. 3	No. 4	No. 5	No.6
Test Code	07222005	08192002	07302003	07232002	07232003	07312004
PARAMETERS						
Fuel Package	Four UL 199 ECLH Fire Test Cribs Ignited by Heptane (96 oz)					
Ceiling Height, ft	10					
Nominal Clearance, ft	7.2					
Ignition Location	Between 2 Offset on Separate Branch Lines					
Sprinkler Type	Upright Standard Spray, Standard Coverage					
Sprinkler Response Type	Quick Response 3 mm Bulb					
Temperature Rating, °F	175					
Nominal Sprinkler Discharge Coefficient K, gpm/psi^{½}	5.6					
Sprinkler Spacing, ft x ft	14 x 14					
Deflector to Ceiling, in	3					
Liquid Type Discharged	Water-Wet System	Water - Dry System**	50% Glycerin Followed by Water	Water-Wet System	50% Glycerin Followed by Water	38% Glycerin Followed by Water
Nominal Total Volume of Antifreeze, gal	0	0	500	0	500	500
Nominal Discharge Pressure, psig	12.3	12.3	13.9	24*	27.2*	26.4*
Target Flow, gpm	19.6	19.6	19.6	27.4	27.4	27.4
Target Discharge Density, gpm/ft^2	0.10	0.10	0.10	0.14	0.14	0.14
RESULTS						
Length of Test, min:s	15:00	15:00	15:00	6:00	15:00	15:00
First Ceiling Sprinkler Operation, min:s	00:35	00:43	00:43	00:39	00:37	00:44
Last Ceiling Sprinkler Operation, min:s	02:14	01:51	03:02	00:45	02:57	02:06
Number of Operated Sprinklers	4	10	12	2	7	5
Nominal Area of Sprinkler Operation, ft^2	784	1960	2352	392	1372	980
Peak Gas Temperature 6 inches Below the Ceiling Above Ignition, °F	707	1130	1213	694	1373	1069
Maximum 1 Minute Average Gas Temperature 6 in. Below the Ceiling Above Ignition, °F	646	941	1089	615	1288	952
Maximum Steel Temperature, ºF	282	493	513	205	639	432
Maximum 1 Minute Average Steel Temperature Above Ignition, °F	262	397	469	192	579	397

*To simulate higher system starting pressure.

** 60 second delay in water delivery from time of first activated sprinkler.

Note: The fuel package was also evaluated with water under 1 sprinkler and between 4 (Test Codes 08192003 and 08032003). In each, 5 or less sprinklers activated.

Table 2: Light Hazard Occupancy Fire Test Summary Table (Metric Units)

FIRE TEST REFERENCE	No. 1	No. 2	No. 3	No. 4	No. 5	No.6
Test Code	07222005	08192002	07302003	07232002	07232003	07312004
PARAMETERS						
Fuel Package	Four UL 199 ECLH Fire Test Cribs Ignited by Heptane (2.84 L)					
Ceiling Height, m	3.05					
Nominal Clearance, m	2.19					
Ignition Location	Between 2 Offset on Separate Branch Lines					
Sprinkler Type	Upright Standard Spray, Standard Coverage					
Sprinkler Response Type	Quick Response 3 mm Bulb					
Temperature Rating, °C	79.4					
Nominal Sprinkler Discharge Coefficient K, L/min/(bar)$^{1/2}$	80					
Sprinkler Spacing, m x m	4.3 x 4.3					
Deflector to Ceiling, mm	76					
Liquid Type Discharged	Water-Wet System	Water - Dry System**	50% Glycerin Followed by Water	Water-Wet System	50% Glycerin Followed by Water	38% Glycerin Followed by Water
Nominal Total Volume of Antifreeze, L	0	0	1893	0	1893	1893
Nominal Discharge Pressure, bar	0.85	0.85	0.96	1.65*	1.87*	1.82*
Target Flow, L/min	74.2	74.2	74.2	103.7	103.7	103.7
Target Discharge Density, L/min/(m)^2	4.07	4.07	4.07	5.70	5.70	5.70
RESULTS						
Length of Test, min:s	15:00	15:00	15:00	6:00	15:00	15:00
First Ceiling Sprinkler Operation, min:s	00:35	00:43	00:43	00:39	00:37	00:44
Last Ceiling Sprinkler Operation, min:s	02:14	01:51	03:02	00:45	02:57	02:06
Number of Operated Sprinklers	4	10	12	2	7	5
Nominal Area of Sprinkler Operation, m^2	72.8	182.1	218.5	36.4	127.5	91.0
Peak Gas Temperature 152 mm Below the Ceiling Above Ignition, °C	375	610	656	368	745	576
Maximum 1 Minute Average Gas Temperature 152 mm Below the Ceiling Above Ignition, °C	341	505	587	324	698	511
Maximum Steel Temperature, ºC	139	256	267	96	337	222
Maximum 1 Minute Average Steel Temperature Above Ignition, °C	128	208	243	89	304	203

*To simulate higher system starting pressure.

**60 second delay in water deliver from time of first activated sprinkler.

Note: The fuel package was also evaluated with water under 1 sprinkler and between 4 (Test Codes 08192003 and 08032003). In each, 5 or less sprinklers activated.

Table 3: Summary of UL's Antifreeze Research – Exposure to Fire

Test	UL Acceptance Criteria Listed Antifreeze Solutions	Test Details	Test Results			
			38% Glycerin	50% Glycerin	30% Propylene Glycol	40% Propylene Glycol
Exposure to fire (Evaluates the resistance to ignition and substantial contribution to the fire)	Not more than a 40 percent increase above the maximum running 15 s average total heat release rate for the nominal 3,000 kW base fire	Test 1 - Nominal K=4.2 SSP 8 ft. ceiling	Compliant – 24.0% increase	Noncompliant- 84.1 % increase	Compliant - 18.4% increase	Not tested – Assumed Noncompliant based upon 50% glycerin test results
		Test 2 - Nominal K=4.2 SSP 20 ft. ceiling	Compliant - 26.9% increase	Noncompliant- >230%* increase	Compliant - 8.5% increase	Not tested – Assumed Noncompliant based upon 50% glycerin test results
		Test 3 - Nominal K=8.0 SSP 8 ft. ceiling	Compliant - 24.1% increase	Compliant- 28.6 % increase	Compliant - 12.9% increase	Not tested – Assumed Compliant based upon 50% glycerin test results
		Test 4 - Nominal K=8.0 SSP 20 ft. ceiling	Compliant - 13.7% increase	Noncompliant - >230%* increase	Compliant - 13.8% increase	Not tested – Assumed Noncompliant based upon 50% glycerin test results

*The calorimeter is calibrated to a maximum of 10 MW, an increase of 230% over the nominal 3MW base line fire.

Table 4: Summary of UL's Antifreeze Research – Residential and Light Hazard

Test	UL Acceptance Criteria Listed Antifreeze Solutions	Test Details	Test Results			
			38% Glycerin	50% Glycerin	30% Propylene Glycol	40% Propylene Glycol
Firefighting Effectiveness — Residential Dwelling Units	Temperature acceptance criteria and not more than 2 operated sprinklers	Test 1 – Nominal K=4.9 Pendent Residential Sprinkler, Low Flow	Compliant based upon 50% test results	Compliant	Compliant based upon 40% test results	Compliant
		Test 2 – Nominal K=4.9 Pendent Residential Sprinkler, 100 psig	Compliant based upon 50% test results	Compliant at 80 and 150 psig	Not Tested - Assumed Compliant based upon glycerin test results	Not Tested - Assumed Compliant based upon glycerin test results
		Test 3 – Nominal K=4.2 Sidewall Residential Sprinkler, Low Flow	Compliant based upon 50% test results	Compliant	Not Tested - Assumed Compliant based upon glycerin test results	Not Tested - Assumed Compliant based upon glycerin test results
		Test 4 – Nominal K=4.2 Sidewall Residential Sprinkler, 100 psig	Compliant based upon 50% test results	Compliant at 80 and 150 psig	Not Tested - Assumed Compliant based upon glycerin test results	Not Tested - Assumed Compliant based upon glycerin test results
Firefighting Effectiveness — Light Hazard Occupancies	Not more than 10 operated sprinklers	Test 1 - Nominal 5.6 SSU Sprinklers, 14 ft. by 14 ft. spacing, 12.3 psig, 175 °F Temperature Rating	Not tested	Noncompliant - 12 Operated Sprinklers	Not Tested	Not Tested
	Not more than 4 operated sprinklers	Test 2 - Nominal 5.6 SSU Sprinklers, 14 ft. by 14 ft. spacing, 24 psig, 175 °F Temperature Rating	Noncompliant - 5 Operated Sprinklers	Noncompliant - 7 Operated Sprinklers	Not Tested	Not Tested

Table 5: Summary of UL's Antifreeze Research -- Ordinary Hazard

Test	UL Acceptance Criteria Listed Antifreeze Solutions	Test Details	38% Glycerin	50% Glycerin	30% Propylene Glycol	40% Propylene Glycol
Firefighting Effectiveness — Ordinary Hazard Occupancies, UL 199 350 lb Wood Crib Fire Test for Sprinklers for greater than 40 gallons[1]	Gas ceiling temperature above fire to be reduced to below 530 °F plus ambient temperature	Single test with four open, nominal 5.6 SSP sprinkler installed on 10 ft by 10 ft. spacing, 15 gpm/sprinkler	Noncompliant- 1462 °F Versus 622 °F Control Temperature	Not Tested – Assumed Noncompliant based upon 38% test results	Noncompliant - 1380 °F Versus 632 °F Control Temperature	Not Tested – Assumed Noncompliant based upon 30% test results

Note 1: At the time of publication of this report, there were no UL Listed antifreeze solutions for ordinary hazard occupancies for volumes greater than 40 gallons.

Table 6: Summary of UL's Antifreeze Research – Exposure to Fire (Metric Units)

Test	UL Acceptance Criteria Listed Antifreeze Solutions	Test Details	Test Results			
			38% Glycerin	50% Glycerin	30% Propylene Glycol	40% Propylene Glycol
Exposure to fire (Evaluates the resistance to ignition and substantial contribution to the fire)	Not more than a 40 percent increase above the maximum running 15 s average total heat release rate for the nominal 3,000 kW base fire	Test 1 – Nominal K=60 SSP, 2.4 m ceiling	Compliant – 24.0% increase	Noncompliant- 84.1 % increase	Compliant – 18.4% increase	Not tested – Assumed Noncompliant based upon 50% glycerin test results
		Test 2 – Nominal K=60 SSP, 6.1 m ceiling	Compliant – 26.9% increase	Noncompliant- >230%* increase	Compliant – 8.5% increase	Not tested – Assumed Noncompliant based upon 50% glycerin test results
		Test 3 – Nominal K=115 SSP, 2.4 m ceiling	Compliant – 24.1% increase	Compliant- 28.6 % increase	Compliant – 12.9% increase	Not tested – Assumed Compliant based upon 50% glycerin test results
		Test 4 – Nominal K=115 SSP, 6.1 m ceiling	Compliant – 13.7% increase	Noncompliant - >230%* increase	Compliant – 13.8% increase	Not tested – Assumed Noncompliant based upon 50% glycerin test results

*The calorimeter is calibrated to a maximum of 10 MW, an increase of 230% over the nominal 3 MW base line fire.

Table 7: Summary of UL's Antifreeze Research – Residential & Light Hazard (Metric Units)

Test	UL Acceptance Criteria Listed Antifreeze Solutions	Test Details	Test Results			
			38% Glycerin	50% Glycerin	30% Propylene Glycol	40% Propylene Glycol
Firefighting Effectiveness — Residential Dwelling Units	Temperature acceptance criteria and not more than 2 operated sprinklers	Test 1 – Nominal K=70 Pendent Residential Sprinkler, Low Flow	Compliant based upon 50% test results	Compliant	Compliant based upon 40% test results	Compliant
		Test 2 – Nominal K=70 Pendent Residential Sprinkler, 6.9 bar	Compliant based upon 50% test results	Compliant at 5.5 and 10.3 bar	Not Tested - Assumed Compliant based upon glycerin test results	Not Tested - Assumed Compliant based upon glycerin test results
		Test 3 – Nominal K=60 Sidewall Residential Sprinkler, Low Flow	Compliant based upon 50% test results	Compliant	Not Tested - Assumed Compliant based upon glycerin test results	Not Tested - Assumed Compliant based upon glycerin test results
		Test 4 – Nominal K=60 Sidewall Residential Sprinkler, 6.9 bar	Compliant based upon 50% test results	Compliant at 5.5 and 10.3 bar	Not Tested - Assumed Compliant based upon glycerin test results	Not Tested - Assumed Compliant based upon glycerin test results
Firefighting Effectiveness — Light Hazard Occupancies	Not more than 10 operated sprinklers	Test 1 - Nominal 80 SSU Sprinklers, 2.4 m by 2.4 m spacing, 0.85 bar, 79.4 °C Temperature Rating	Not tested	Noncompliant - 12 Operated Sprinklers	Not Tested	Not Tested
	Not more than 4 operated sprinklers	Test 2 - Nominal 80 SSU Sprinklers, 2.4 m by 2.4 m spacing, 1.65 bar, 79.4 °C Temperature Rating	Noncompliant - 5 Operated Sprinklers	Noncompliant - 7 Operated Sprinklers	Not Tested	Not Tested

Table 8: Summary of UL's Antifreeze Research - Ordinary Hazard (Metric Units)

Test	UL Acceptance Criteria Listed Antifreeze Solutions	Test Details	38% Glycerin	50% Glycerin	30% Propylene Glycol	40% Propylene Glycol
Fire Fighting Effectiveness – Ordinary Hazard Occupancies, UL 199 159 kg Wood Crib Fire Test for Sprinklers for greater than 151 liters[1]	Gas ceiling temperature above fire to be reduced to below 530 °F plus ambient temperature	Single test with four open, nominal 80 SSP sprinkler installed on 3.0 m by 3.0 m spacing, 56.8 L/min per sprinkler	Noncompliant- 794 °C Versus 328 °C Control Temperature	Not Tested – Assumed Noncompliant based upon 38% test results	Noncompliant – 749 °C Versus 333 °C Control Temperature	Not Tested – Assumed Noncompliant based upon 30% test results

Note 1: At the time of publication of this report, there were no listed antifreeze solutions for ordinary hazard occupancies for volumes greater than 40 gallons.

Notice

Publication	
Publication Date	September 16, 2020
Report Keywords	antifreeze, sprinklers, systems, glycerin, propylene glycol, light hazard, ordinary hazard, residential, standard spray

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Table of Unit Conversions

Length	1 ft = 0.305 m 1 in. = 25.4 mm
Area	1 ft^2 = 0.0929 m^2
Volume	1 fl oz = 0.0296 L 1 gal = 3.78 L
Volumetric Flow Rate	1 SCFM = 0.0283 m^3/min 1 gpm = 3.78 L/min
Mass	1 lb = 0.454 kg
Temperature	(#°F – 32) x 5/9 = #°C
Sprinkler Discharge k Factor	1 gpm/$psi^{1/2}$ = 14.4 L/min/$bar^{1/2}$
Sprinkler Discharge Density	1 gpm/ft^2 = 40.746 L/min/m^2
Pressure	1 psi = 0.0689 bar

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Introduction

In 2009, a fire incident in Truckee, California, raised concerns regarding the ignitability and combustibility of high concentrations of antifreeze solutions that had been used in sprinkler systems for more than 60 years. This incident involved a cooking oil fire in a kitchen where a sprinkler system with a high concentration of a glycerin antifreeze solution deployed and reportedly caused an explosion that resulted in a fatality as well as a serious injury.

After this event, several research initiatives were immediately undertaken to better understand the concerns associated with the use of glycerin and propylene glycol antifreeze solutions used in sprinkler systems. In 2010, Underwriters Laboratories conducted a series of tests that demonstrated the potential for high concentrations of these solutions to ignite and substantially contribute to a fire. Subsequent to UL's research, the National Fire Protection Association (NFPA) initiated further research with the Fire Protection Research Foundation (FPRF) to learn more about the concerns associated with the use of these antifreeze solutions in sprinkler systems.

The primary focus of the FPRF research was to gain an improved understanding of the conditions under which these solutions had the potential to ignite and substantially contribute to a fire. Testing was conducted to evaluate the ability of a 50 percent solution of glycerin and 40 percent solution of propylene glycol to control a furniture type fire when discharged from residential sprinklers. However, no testing was conducted to investigate the ability of standard spray sprinklers discharging these solutions to control fires of the types and sizes they are intended to protect. The following is a list of research reports that have been issued by the Fire Protection Research Foundation (FPRF) related to the use of antifreeze in sprinkler systems.

- Antifreeze Systems in Home Fire Sprinkler Systems — Literature Review and Research Plan, Fire Protection Research Foundation, June 2010. [5]
- Antifreeze Systems in Home Fire Sprinkler Systems — Phase II Final Report, Fire Protection Research Foundation, December 2010. [6]
- Antifreeze Solutions Supplied through Spray Sprinklers — Final Report, Fire Protection Research Foundation, November 2012. [7]

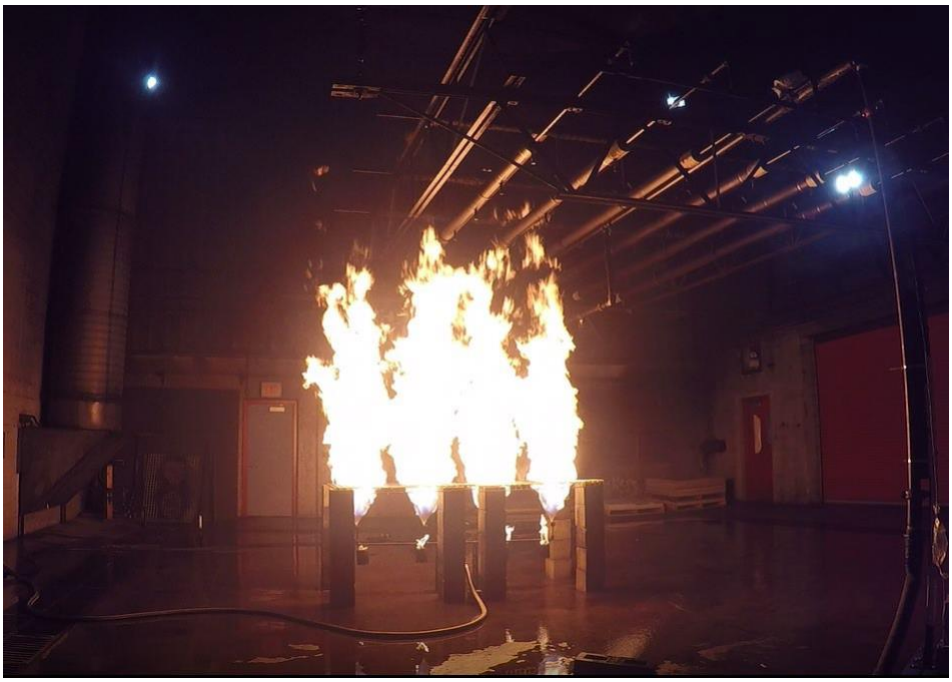
An overview of the FPRF research and test results are included in Table A.5.3.4.4.1(2) of the 2020 Edition of NFPA 25.

This research initiative covered in this report was undertaken to develop data and information to better understand the ability of certain glycerin and propylene glycol antifreeze solutions to effectively control a fire in a light or ordinary hazard occupancy when discharged from a standard spray sprinkler. Data generated from this research included information on the temperatures measured at the ceiling and a determination of the number of operated sprinklers during specific fire scenarios.

Ignitability – UL 2901 exposure to fire test

In the FPRF research, the ignitability of an antifreeze solution was evaluated by discharging the solution through a sprinkler over a heptane spray burner using standard spray sprinklers with an increasing pressure starting at 10 psig. This test method became the basis of UL 2901's Exposure to Fire Test. The UL 2901 test protocol includes a series of four evaluations with nominal K4.2 and K8.0 sprinklers at heights of 8 ft and 20 ft above the floor. Photos of a test before and during antifreeze discharge are shown in Figure 1.

A 50 percent glycerin solution was evaluated using a heptane spray burner during the FPRF research, which was considered representative of 40 percent propylene glycol solution. No testing was conducted with 40 percent propylene glycol using standard spray sprinklers. UL has since evaluated 38 percent glycerin and 30 percent propylene glycol solutions in accordance with the UL 2901 Exposure to Fire Test. These solutions are currently permitted in existing systems as referenced in NFPA 25. The data generated is summarized in Table 9 and Table 10. Both solutions yielded compliant test results as compared to the current acceptance criteria in UL 2901.



Before antifreeze discharge

During antifreeze discharge

Figure 1: Photos of the UL 2901 exposure to fire test before and during antifreeze discharge

Table 9: 38% glycerin UL 2901 exposure to fire test results summary

Solution Evaluated:	**38% Glycerin / 62% Water**

	Test Parameters			**Test Results**				
Test Number	Test Date/Code	Sprinkler K-Factor	Distance of Sprinkler Deflector to Test Room Floor	15 second maximum average of Free Burn HRR (kW) HRR_{15avg}	Acceptance Criteria (kW) (40% Above Free Burn Max. Average)	15 second maximum average during discharge HRR (kW) HRR_{15avg}	Percent difference between 15 second maximum running average of discharge versus free burn (%)	Acceptable? (15 second running average of discharge < acceptance criteria)
10	06221802	4.2	8 ft	3112	4357	3860	24.0	Y
1	06211801	4.2	20 ft	3132	4385	3975	26.9	Y
7	06211807	8.0	8 ft	2980	4172	3700	24.1	Y
4	06211804	8.0	20 ft	2980	4172	3387	13.7	Y

Table 10: 30% propylene glycol UL 2901 exposure to fire test results summary

Solution Evaluated:	**30% Propylene Glycol -- 70% Water**

	Test Parameters			**Test Results**				
Test Number	Test Date/Code	Sprinkler K-Factor	Distance of Sprinkler Deflector to Test Room Floor	15 second maximum average of Free Burn HRR (kW) HRR_{15avg}	Acceptance Criteria (kW) (40% Above Free Burn Max. Average)	15 second maximum average during discharge HRR (kW) HRR_{15avg}	Percent difference between 15 second maximum running average of discharge versus free burn (%)	Acceptable? (15 second running average of discharge < acceptance criteria)
11	06221803	4.2	8 ft	3089	4325	3656	18.4	Y
2	06211802	4.2	20 ft	3197	4476	3469	8.5	Y
8, 8a*	06211808 (10 to 70 psig) 06221801 (60 to 100 psig)	8.0	8 ft	3104	4346	3506	12.9	Y
5	06211805	8.0	20 ft	2946	4124	3353	13.8	Y
Notes:	*The pump started to decline in pressure after achieving 70 psig. The heat release was low at this point. Test 8a was subsequently conducted, where we started at 60 psig and ramped up to complete the test							

Residential occupancies – UL 2901 residential fire tests

Four residential type fire tests are required to evaluate antifreeze solutions for residential occupancies as described in UL 2901. The parameters for the four tests are summarized in Table 11. These tests were selected for inclusion in UL 2901 based on equivalent tests conducted in the FPRF research [5].

In residential fire tests, a fire is initiated by igniting both a small wood crib located near combustible plywood wall paneling and simulated furniture in the corner of a room with two sprinklers installed within the room and a third near a doorway. An image of the test setup is shown in Figure 2. The test compliance criteria are:

1. A maximum of two residential sprinklers shall operate. [4]
2. The sprinklers shall limit temperatures as follows:

   a) The maximum temperature 3 inches (76 mm) below the ceiling shall not exceed 600°F (316°C).

   b) The maximum temperature 5-1/4 feet (1.6 m) above the floor shall not exceed 200°F (93°C).

   c) The temperature at the location described in (b) shall not exceed 130°F (54°C) for more than any continuous 2-minute period.

   d) The maximum ceiling material temperature 1/4 inch (6.4 mm) behind the finished ceiling surface shall not exceed 500°F (260°C). [4]

In the FPRF research, both 50 percent glycerin and 40 percent proplyene glycol solutions were evaluated [5]. The test results for the UL 2901 equivalent tests are provided in Table 11. All tests were compliant.

Table 11: UL 2901 Sec. 19.1 Test Parameters & Legacy Antifreeze Test Results

Test Details	Test Results	
	50% Glycerin	**40% Propylene Glycol**
Test 1 – Nominal K=4.9 Pendent Residential Sprinkler, Low Flow	Compliant	Compliant
Test 2 – Nominal K=4.9 Pendent Residential Sprinkler, 100 psig	Compliant at 80 and 150 psig	Not Tested -Assumed Compliant based upon glycerin test results
Test 3 – Nominal K=4.2 Sidewall Residential Sprinkler, Low Flow	Compliant	Not Tested -Assumed Compliant based upon glycerin test results
Test 4 – Nominal K=4.2 Sidewall Residential Sprinkler, 100 psig	Compliant at 80 and 150 psig	Not Tested -Assumed Compliant based upon glycerin test results

Figure 55.7

Fire test arrangement – residential sidewall sprinklers, test arrangement No. 1

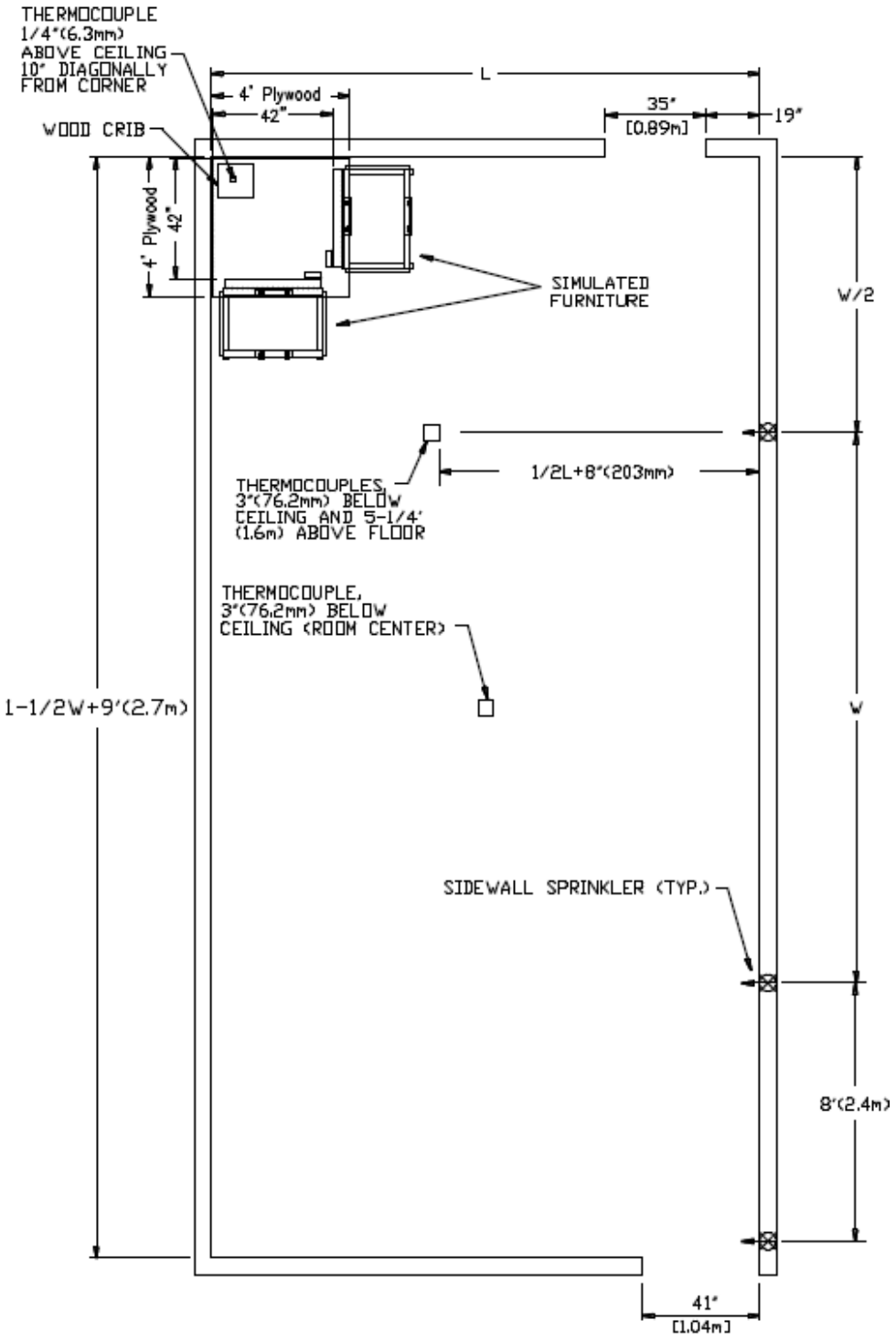


Figure 2: UL 199 Figure 55.7 [4] depicting the test layout used in the UL 2901 Sec. 19

Light hazard occupancy fire testing

Testing conducted at the UL large-scale fire test facility located in Northbrook, Illinois.

Large-scale fire test building

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 control and suppression characteristics of automatic water sprinkler systems. A schematic of the test facility is shown in Figure 3.

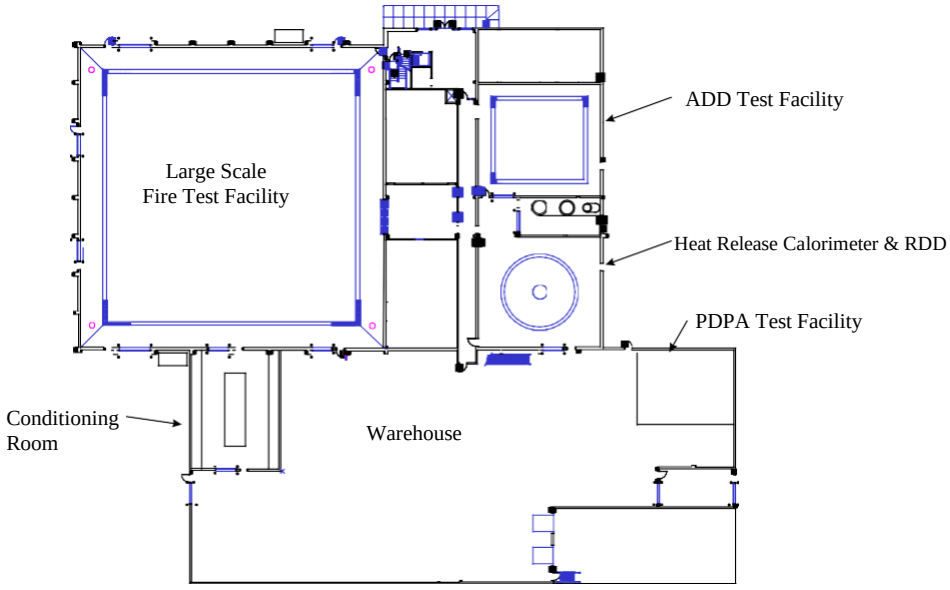


Figure 3: Large Scale Test Facility

Large-scale fire test facility

Testing was conducted in the120-foot-by-120-foot main fire test cell. The cell is equipped with a 100 ft. by 100 ft. smooth, non-combustible adjustable ceiling. The 10 ft. perimeter between the adjustable ceiling and the walls of the test room simulates a larger space by not allowing a hot gas layer to accumulate under the adjustable ceiling.

The center 100 ft. by 100 ft. floor area of the test facility is smooth, flat concrete and is surrounded with a grated drainage trench to ensure water drainage from the test area. The water from the suppression system is collected, contained and filtered through a nominal 180,000-gallon water treatment system.

The large-scale test cell used in this investigation is equipped with an exhaust system capable of a maximum flow of 60,000 cubic feet per minute through a smoke abatement

system. Natural make-up air was provided through four inlet ducts positioned along the

wall of the test facility. The fresh air is released into the room approximately 10 feet above the floor level through straightening screens. This ventilation arrangement provides adequate air so that fire growth occurs naturally.

All products of combustion from the tests were contained within the test facility and processed through a regenerative thermal oxidizing system.

Heat release calorimeter

The heat release calorimeter is in a nominal 50-foot-by-50-foot fire test cell equipped with a 25-foot diameter collection hood.

Four inlet ducts provide make up air in the test facility and are located at the walls 5-foot above the test floor to minimize any induced drafts during the fire tests.

The center of the floor of the test facility is 30-foot-by-30-foot, is smooth and flat, and is surrounded with a grated drain to insure adequate floor water drainage from the test area.

Automatic sprinkler system

A wet pipe automatic sprinkler system was installed below the adjustable ceiling and arranged to provide a constant nominal flowing pressure at the sprinklers. The adjustable ceiling was positioned to 10 ft above floor level.

A schematic of the sprinkler system is shown in Figure 4. The piping system was composed of two sections. The inner section consisted of 24 sprinklers installed on four 2 ½-in. diameter, schedule 40 branch lines. The sprinklers were quick response, standard spray upright type having a nominal K-factor of 5.6 gpm/psig$^{1/2}$, a 175°F temperature rating and a ½ inch NPT inlet thread. The sprinklers were installed on 14-foot by 14-foot spacing with the deflector located nominally 3 in. below the moveable ceiling. The branch lines were supplied through a 4-in. cross main and a 6-in. main line by a variable speed pump capable of supplying the required constant flowing pressure throughout the course of a test.

The total piping volume of the inner section was designed to be nominally 500 gallons. In the antifreeze tests, the inner section system volume was charged with antifreeze then continually pressurized with water during a test, such that water was discharged after the antifreeze was expelled in the path to the operating sprinklers. Between tests, the system could be isolated from the variable speed pump using a control valve and a dead-end section of pipe was used to fill the system with antifreeze solutions if required for the test.

The outer section of the system was pressurized with water and hydraulically isolated from the inner section. It consisted of two branch lines with six sprinklers each, bringing the total number of sprinklers to 36. The purpose of the outer section was to provide indication of sprinkler activation in an area where the spray pattern does not affect the fuel package.

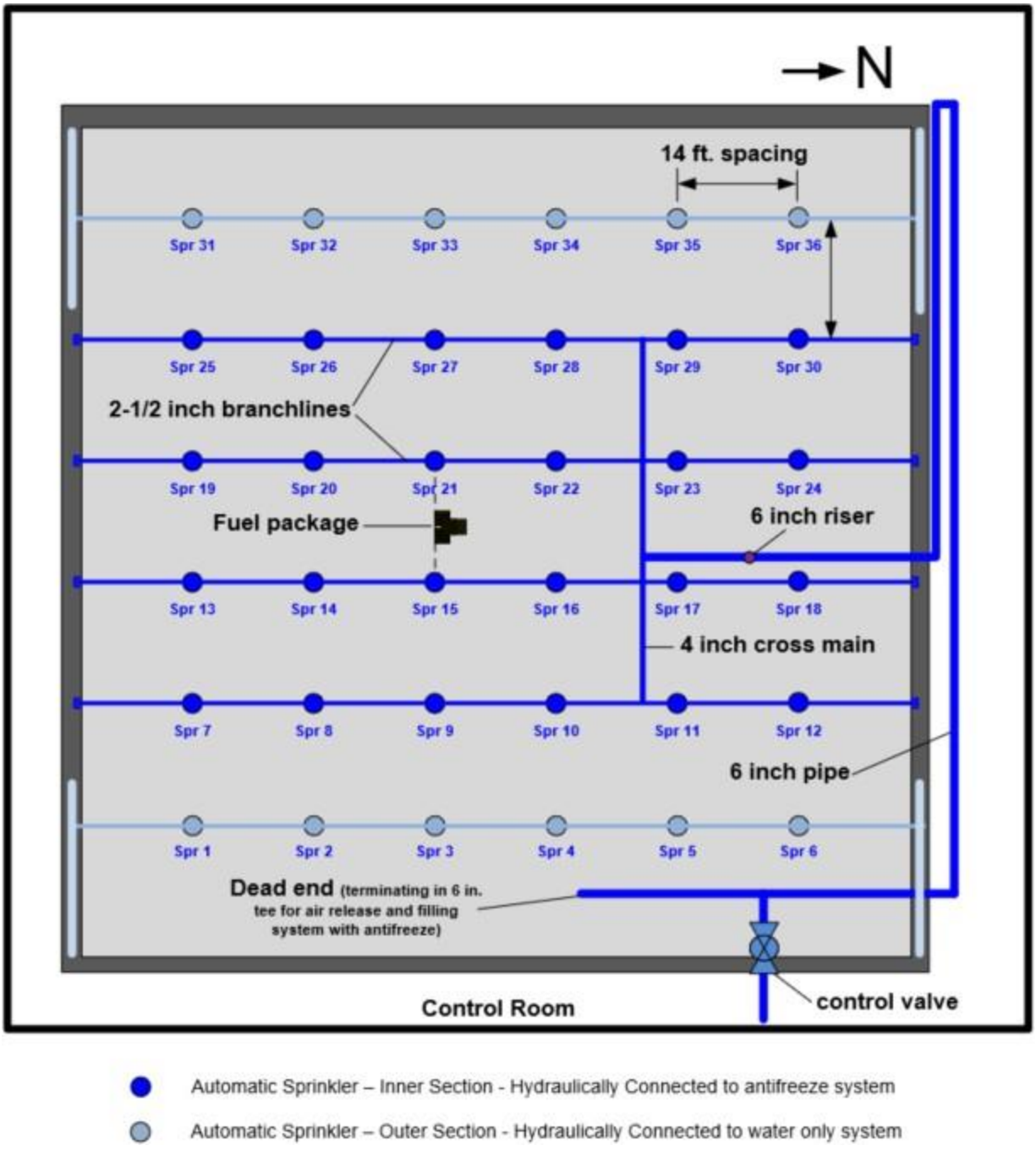


Figure 4: Automatic sprinkler system in large scale test facility

Instrumentation

Steel beam temperature

A 4-foot long by 2-inhes wide by 2-inches high steel angle was mounted at ceiling level, above and adjacent to the fuel package. The temperature of the steel beam was measured with five embedded Type K thermocouples spaced evenly within the beam. The steel beam location relative to the fuel package is shown in Figure 5.

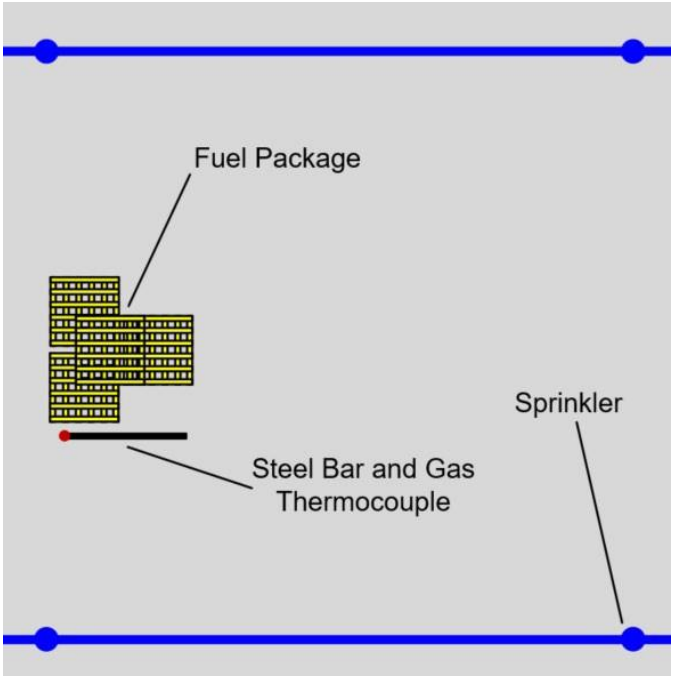


Figure 5: Fuel Package and Steel Bar Placement

Gas temperature

The gas temperature adjacent to each sprinkler was measured with a 0.0625-in. diameter Inconel sheathed Type K thermocouple. The gas temperature below the steel beam was measured with a Type K thermocouple located 6 inches below ceiling level.

Pipe flow pressure

The pressure in the piping system was monitored and fed back to the variable speed pump to maintain system pressure and flow.

Video

Two video cameras were used to record testing. One camera was positioned at floor level near the Northwest corner of the laboratory floor and one camera was positioned on the East side at floor level. In addition, two infrared cameras were used to record the tests from the East side at floor level and the Northwest corner.

Data collection

All data was collected using an electronic data acquisition system at a one-second scan rate.

Calorimeter

The calorimeter consists of a 25-ft. diameter collection hood connected to an exhaust system capable of 60,000 SCFM.

The heat release calorimeter is equipped with convective and total heat release instrumentation. The convective instrumentation calculates the heat release rate from the energy rise of the products of combustion entering the calorimeter. The total heat release instrumentation calculates fire size using oxygen consumption techniques.

The heat release calorimeter has been calibrated to a maximum total heat release rate of 10 MW. Any reported heat release rates greater than 10 MW are underestimated because not all products of combustion were collected.

Fuel package

A representative light hazard fuel package was developed using wood cribs and pans of heptane (Figure 6). The package consisted of four 20-inches-by-20-inches-by-15-inches wood cribs constructed with nominal 2-in wood members and three 16-inches-by-16-inches-by-4-inches steel pans filled with 32 oz of heptane each. Three cribs were placed 1 inch apart in a three by one arrangement with one pan of heptane supporting each crib. The fourth crib was centered on top. Each crib weighed approximately 33 pounds.

Figure 6: Representative light hazard fuel package

Fuel package total heat release rate

The heat release rate of the fuel package was measured. The resulting heat release rate curve is given in Figure 7. The fuel package achieved a peak total heat release rate of 2.5 MW. A photo of the burning fuel package is shown in Figure 8.

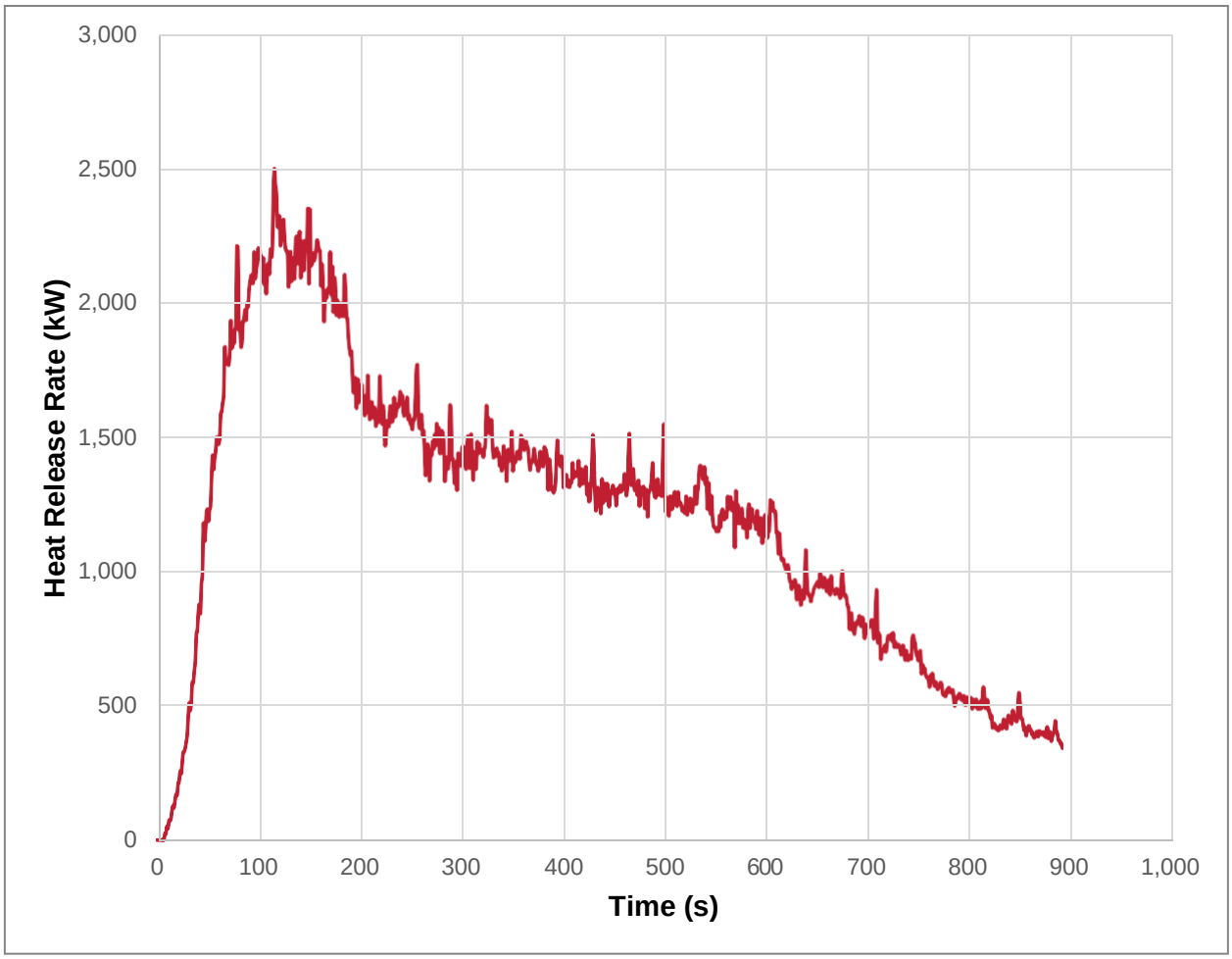


Figure 7: Fuel package total heat release rate

Figure 8: Burning fuel package under calorimeter

Light hazard office workstation heat release rates

Typical light hazard fuel loads are those found in office buildings and other facilities as referenced in NFPA 13. “Institutional” and “office” spaces are given as examples of light hazard occupancies in Annex A of NFPA 13. Based on this assessment, the fuel package heat release rate was compared to existing data collected from free burn experiments of single office workstations [8-11]. Figure 9 shows a compilation of heat release rate curves produced from studies conducted at the National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland, and the National Research Institute for Fire and Disaster (NRIFD) in Japan between 1992 and 2004. The studies entailed various workstation sizes, fuel loads and degrees of encapsulation, i.e., two, three or four-sided cubicles.

Figure 10 indicates that the representative light hazard fuel package resembles the peak and decay phase of the average heat release rate curve for the work station fires illustrated in Figure 9 when the peak is shifted back to remove the growth phase, which is shown in negative “pre-test” time.

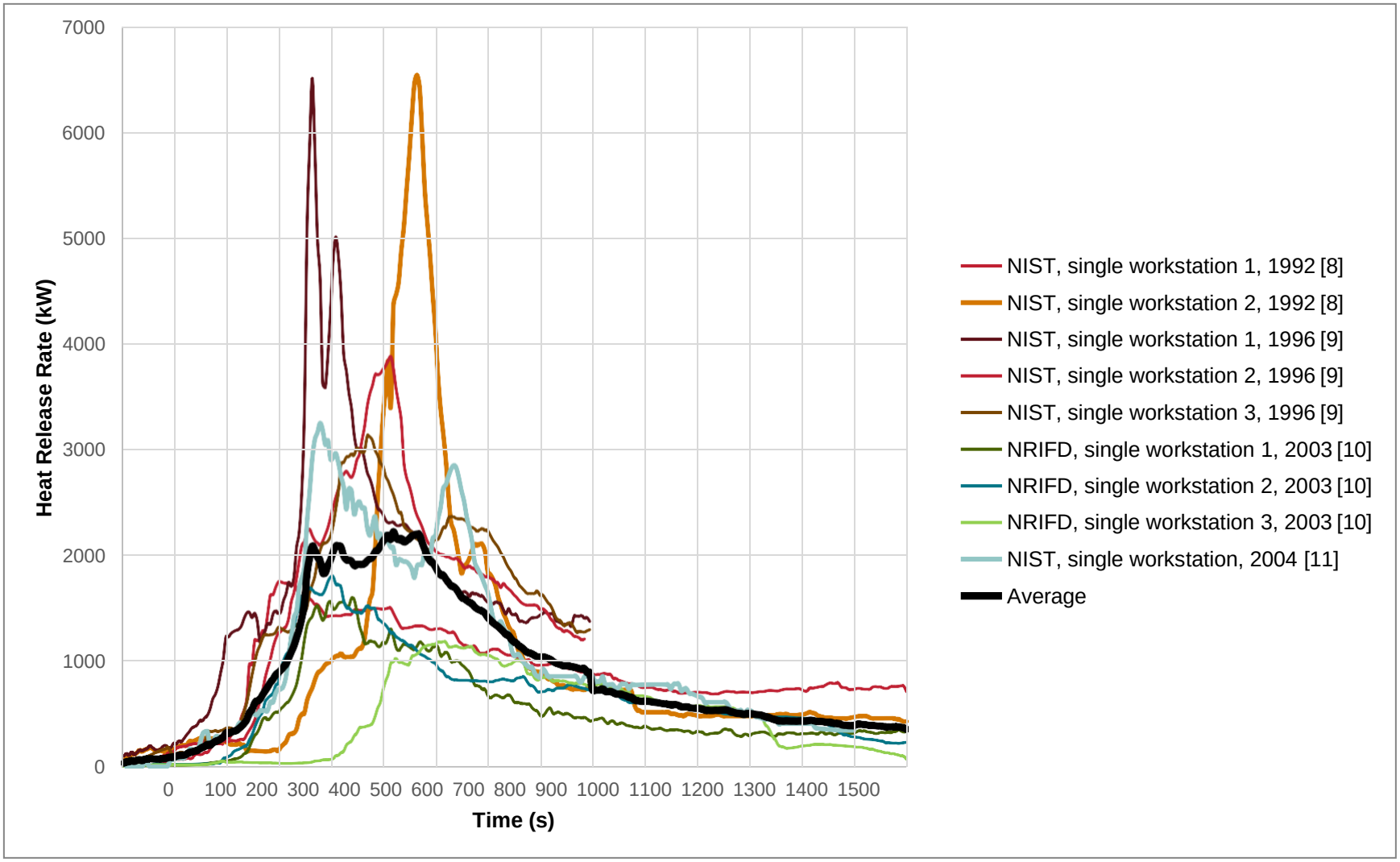


Figure 9: Office workstation literature total heat release rate data

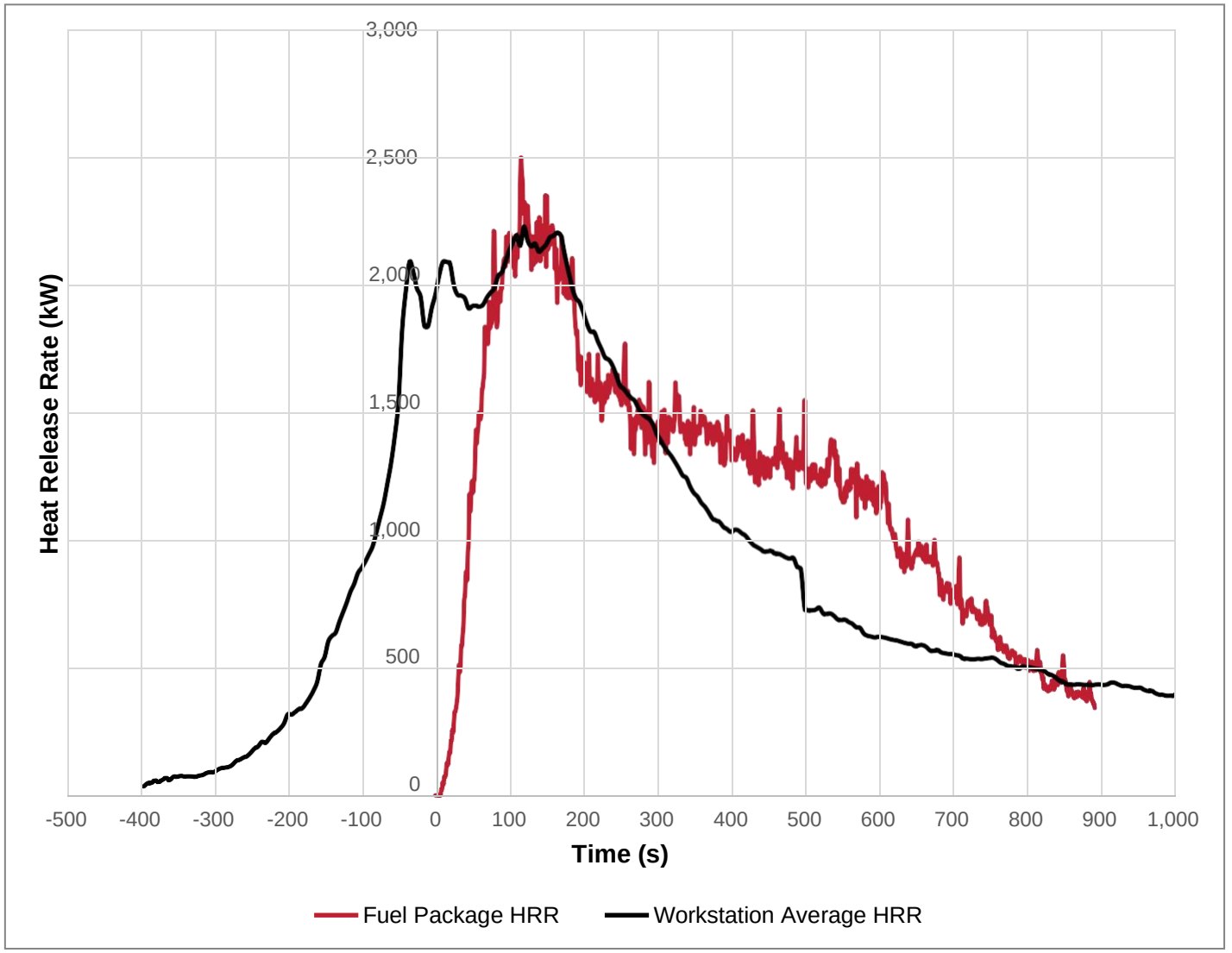


Figure 10: Test fuel package compared to average workstation total HRR curve

Free-burn sprinkler activation

A baseline free burn of the fuel package was conducted under the sprinkler system. The system piping was not charged or pressurized and individual sprinkler activation times were not recorded. Figure 11 shows that the fuel package activated 21 of 36 sprinklers during its free-burn period.

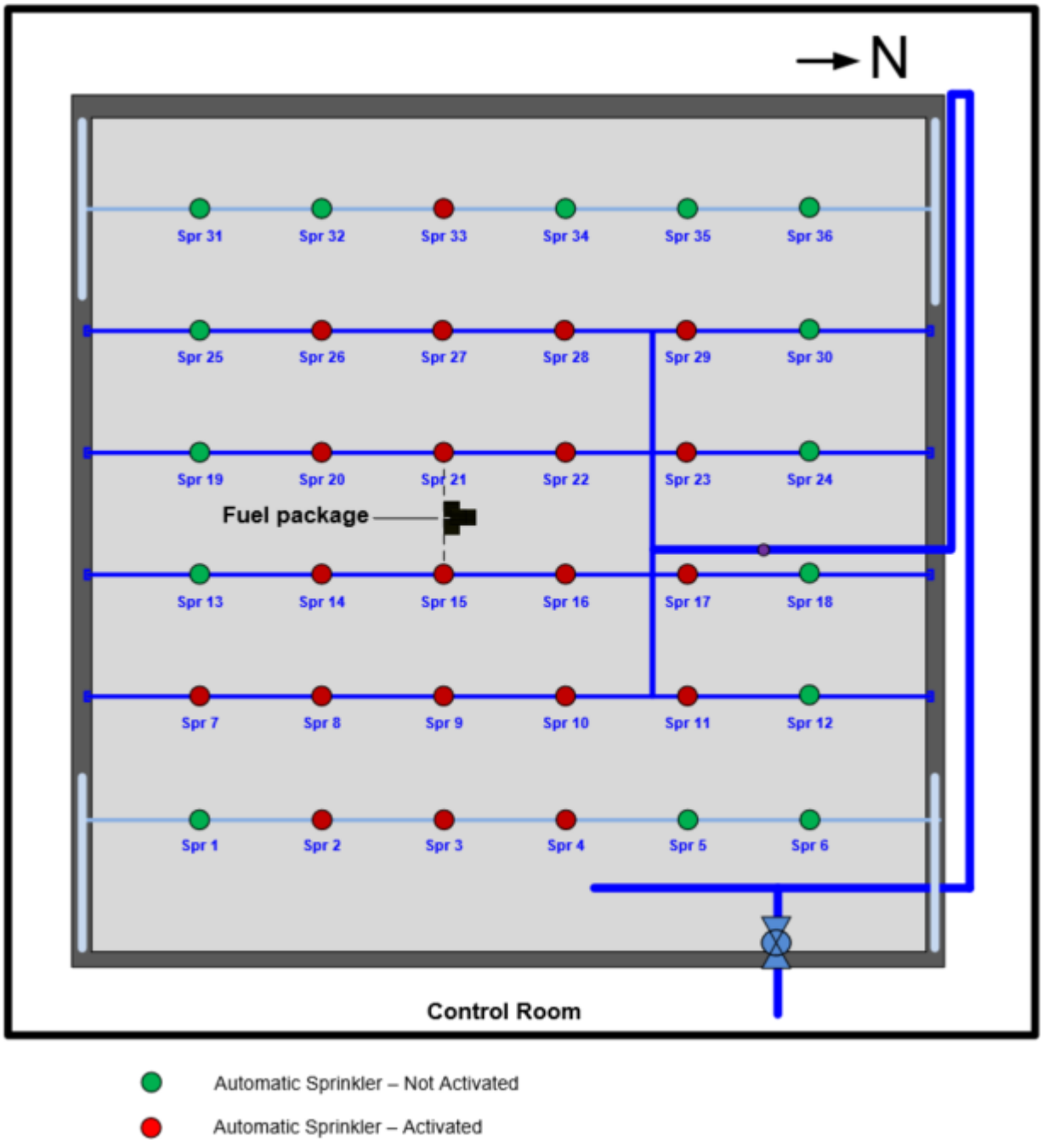


Figure 11: Fuel package free-burn sprinkler activation

Selection of fuel package

The fuel package used in the light hazard testing series was selected based upon the following characteristics:

- It demonstrated heat release rate characteristics comparable to the heat release rate generated from office type fires.
- It generated sufficient energy to operate more than 20 sprinklers located on a 14 ft. by 14 ft. spacing which correlates to a sprinkler operation area greater than 4,000 ft^2.
- The composition of the fuel package utilizes a combination of wood crib and heptane elements that are referenced in UL 199 for Extended Coverage Light Hazard fire testing.
- It created a fire that has been demonstrated to be controlled by a UL Listed sprinkler discharging water at a discharge density consistent with the design density for light hazard occupancies referenced in NFPA 13 (0.10 gpm/ft^2).
- It provided some shielding of combustible materials and surfaces.
- It utilized a small quantity of flammable liquid (less than a gallon total), that may be used by an arsonist.
- The use of a flammable liquid accelerant below the wood cribs can be representative of the pooling of a liquid fuel such as melted plastics.
- It provided reproducible test results that compare the firefighting performance of antifreeze solutions to water in terms of ceiling temperatures and number of operated sprinklers.

Antifreeze solutions

Two concentrations of glycerin antifreeze solutions were used during the light hazard type fire testing, 38 percent and 50 percent. To maintain the sprinkler discharge densities, the test pressures were calculated using an adjusted discharge coefficient (K-factor). The equations are given in Eqtn 1 and 2. A summary of the sprinkler discharge densities and pressures are provided in Table 12.

$$kk_{AA} = 7.94 kk_{WW} \sqrt{\frac{1}{\gamma\gamma_{AA}}} \qquad EEEEEEEE\,1$$

$$PP_{AA} = \left(\frac{QQ}{kk_{AA}}\right)^{2} \qquad EEEEEEEE\,2$$

Where k_A is the adjusted sprinkler k-factor for discharge of antifreeze, k_W is the sprinkler k-factor for water, γ_A is the antifreeze density (lb/ft^3), Q is the sprinkler discharge rate (gpm), and P_A is the adjusted discharge pressure for antifreeze.

Table 12: Summary of test discharge densities and pressures

Solution	Discharge Density (gpm/ft^2)	Sprinkler Flow (gpm)	Specific Gravity at 60°F	Fluid Density (lb/ft^3)	K_A	Discharge Pressure (psi)
Water	0.1	19.6	N/A	N/A	N/A	12.3
50% Glycerin	0.1	19.6	1.1437	71.4	5.26	13.9
Water	0.14	27.4	N/A	N/A	N/A	24.0
38% Glycerin	0.14	27.4	1.1122	69.4	5.34	26.4
50% Glycerin	0.14	27.4	1.1437	71.4	5.26	27.2

Test procedure

Six light hazard type fire tests were conducted as described in Table 13. Tests were conducted with water and with antifreeze solutions at two different discharge densities. The minimum density for the light hazard application per NFPA 13 (0.10 gpm/ft^2) was evaluated along with an increased density of 0.14 gpm/ft^2 to simulate a higher starting pressure. For the wet system test using water and antifreeze solutions, the sprinklers discharged the water or antifreeze solution immediately upon sprinkler operation. For the simulated dry system using water, the discharge of water was delayed 60 seconds after the first sprinkler activated.

The fuel package was located offset, between two sprinklers with the leading edge of the fuel package flush with the sprinkler centerline (Figure 4). The sprinkler system was charged with the discharged liquid (water or antifreeze) to the required discharge pressure. Time zero for each test was marked by ignition of the heptane.

During testing, the system pump was used to maintain the target discharge pressure at each operating sprinkler. Times of sprinkler activation were determined by temperature measurements of the thermocouples installed adjacent to each sprinkler, which indicate a sharp temperature drop when water or antifreeze is discharged. Testing was concluded after 15 minutes or when the fuel package was extinguished. The activated sprinklers were also visually confirmed either during or after the test.

Seven frames from a test video (visual and infrared) are presented in Appendix A: Example Test Video Frames. The frames show the progression from the ignition of the fuel package up until final manual extinguishment of the fuel package at 15 minutes. The example presented is Test No. 3.

Table 13: Light hazard test parameters

FIRE TEST REFERENCE	No. 1	No. 2	No. 3	No. 4	No. 5	No.6
Test Code	07222005	08192002	07302003	07232002	07232003	07312004
PARAMETERS						
Fuel Package	Four UL 199 ECLH Fire Test Cribs Ignited by Heptane (96 oz)					
Ceiling Height, ft	10					
Nominal Clearance, ft	7.2					
Ignition Location	Between 2 Offset on Separate Branch Lines					
Sprinkler Type	Upright Standard Spray, Standard Coverage					
Sprinkler Response Type	Quick Response 3 mm Bulb					
Temperature Rating, °F	175					
Nominal Sprinkler Discharge Coefficient K, gpm/psi$^{1/2}$	5.6					
Sprinkler Spacing, ft x ft	14 x 14					
Deflector to Ceiling, in	3					
Liquid Type Discharged	Water-Wet System	Water - Dry System**	50% Glycerin Followed by Water	Water-Wet System	50% Glycerin Followed by Water	38% Glycerin Followed by Water
Nominal Total Volume of Antifreeze, gal	0	0	500	0	500	500
Nominal Discharge Pressure, psig	12.3	12.3	13.9*	24	27.2*	26.4*

*To simulate higher system starting pressure.
**60 sec delay in water delivery from time of first activated sprinkler.

Results

The sprinkler response times and the maximum gas temperatures at each sprinkler for each test are provided in Tables 14 through 25. Figures 12 through 17 include information on the sprinkler layout and sprinkler activation.

Test No.1 – Water at 12.3 psi

Table 14: Test No.1 Sprinkler response times (mm:ss)

Sprinkler 31..36	N/A	N/A	N/A	N/A	N/A	N/A
Sprinkler 25..30	N/A	N/A	N/A	N/A	N/A	N/A
Sprinkler 19..24	N/A	N/A	**00:36**	**02:14**	N/A	N/A
Sprinkler 13..18	N/A	N/A	**00:42**	**01:24**	N/A	N/A
Sprinkler 7..12	N/A	N/A	N/A	N/A	N/A	N/A
Sprinkler 1..6	N/A	N/A	N/A	N/A	N/A	N/A

Table 15: Test No.1 Maximum gas temperatures near sprinklers (°F)

Sprinkler 31..36	145	136	127	151	145	136
Sprinkler 25..30	162	194	145	187	169	140
Sprinkler 19..24	154	199	**259**	**219**	185	149
Sprinkler 13..18	154	190	**257**	**255**	174	144
Sprinkler 7..12	151	142	169	198	158	135
Sprinkler 1..6	118	117	138	147	142	124

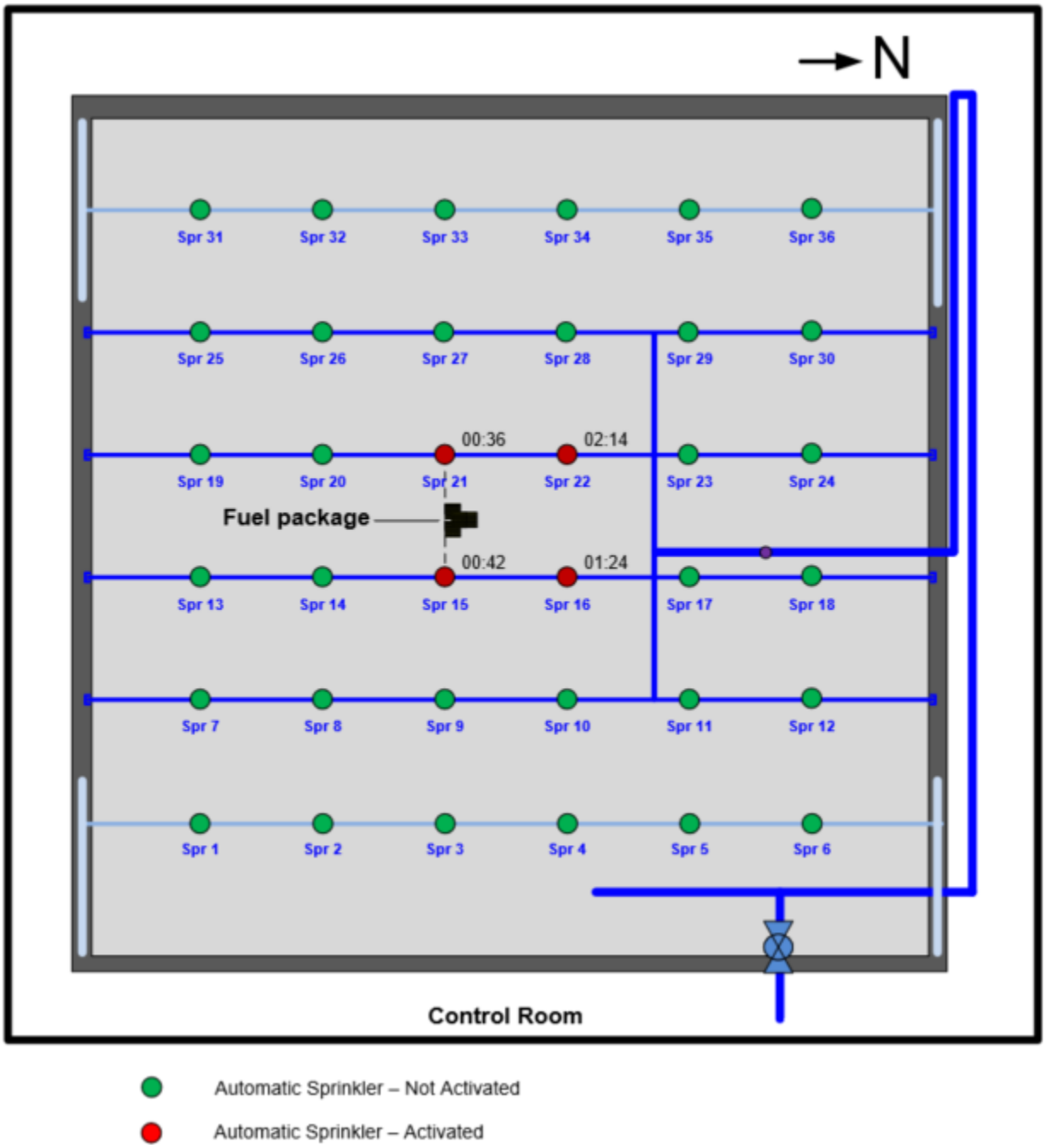


Figure 12: Test No.1 sprinkler activation diagram

Test No. 2 – Dry system simulation with water @ 12.3 psi

Table 16: Test No.2 sprinkler response times (mm:ss)

Sprinkler 31..36	N/A	N/A	N/A	N/A	N/A	N/A
Sprinkler 25..30	N/A	N/A	**01:47**	**01:51**	N/A	N/A
Sprinkler 19..24	N/A	**01:48**	**00:43**	**01:44**	N/A	N/A
Sprinkler 13..18	N/A	**01:43**	**00:50**	**01:15**	N/A	N/A
Sprinkler 7..12	N/A	**N/A**	**01:43**	**01:43**	N/A	N/A
Sprinkler 1..6	N/A	N/A	N/A	N/A	N/A	N/A

Table 17: Test No.2 maximum gas temperatures near sprinklers (°F)

Sprinkler 31..36	147	167	192	180	165	147
Sprinkler 25..30	171	185	**243**	**241**	198	167
Sprinkler 19..24	192	**275**	**417**	**286**	216	181
Sprinkler 13..18	198	**253**	**390**	**311**	201	169
Sprinkler 7..12	174	210	**248**	**244**	214	171
Sprinkler 1..6	151	171	185	171	171	138

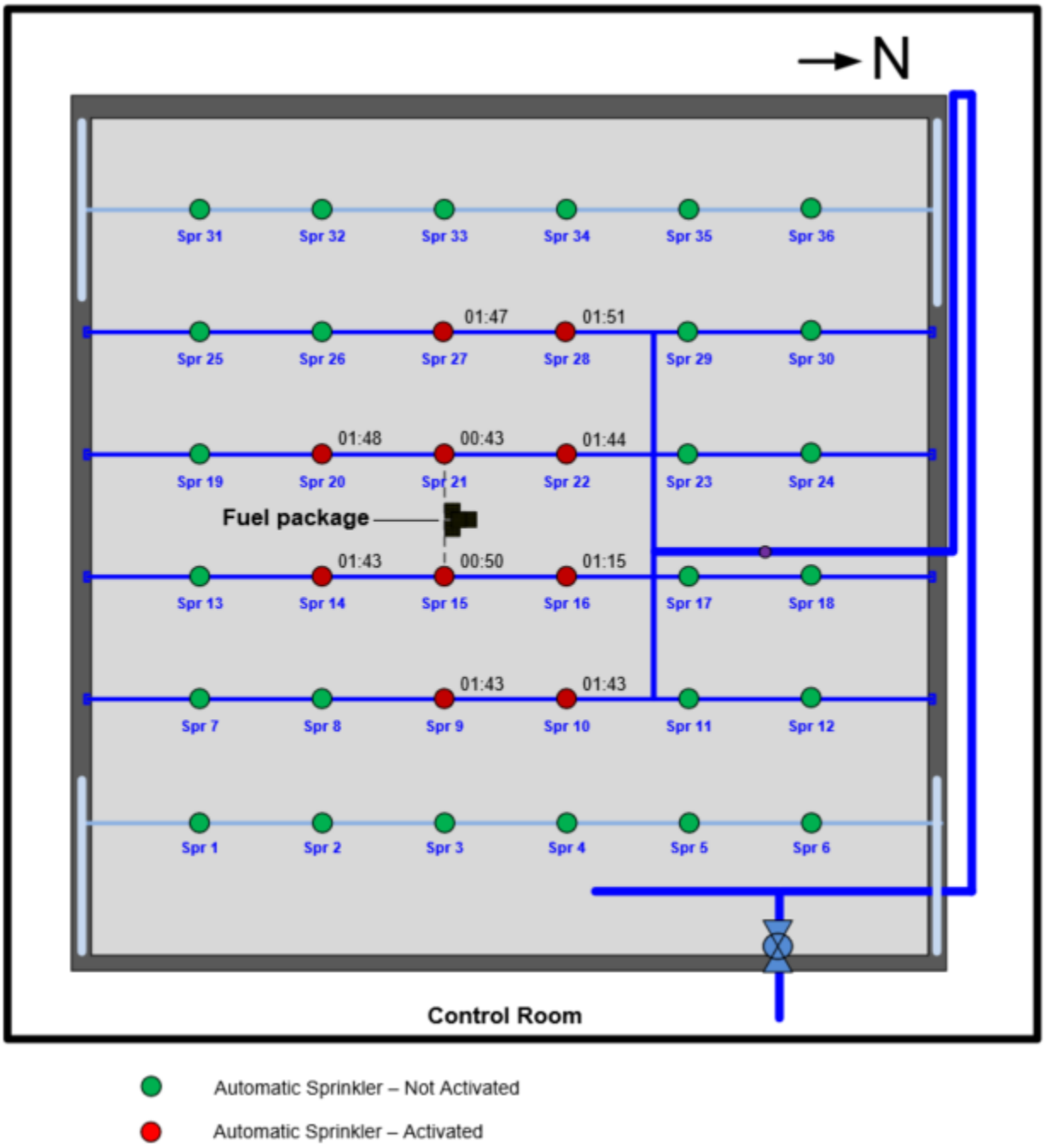


Figure 13: Test No.2 sprinkler activation diagram

Test No.3 – 50% glycerin antifreeze at 13.9 psi

Table 18: Test No.3 sprinkler response times (mm:ss)

Sprinkler 31..36	N/A	N/A	N/A	N/A	N/A	N/A
Sprinkler 25..30	N/A	**03:02**	**02:17**	**02:22**	N/A	N/A
Sprinkler 19..24	N/A	**01:41**	**00:43**	**01:21**	N/A	N/A
Sprinkler 13..18	N/A	**01:49**	**00:43**	**01:27**	N/A	N/A
Sprinkler 7..12	N/A	**02:44**	**02:29**	**02:02**	N/A	N/A
Sprinkler 1..6	N/A	N/A	N/A	N/A	N/A	N/A

Table 19: Test No.3 maximum gas temperatures near sprinklers (°F)

Sprinkler 31..36	156	181	180	178	167	140
Sprinkler 25..30	176	**212**	**228**	**230**	181	149
Sprinkler 19..24	171	**219**	**250**	**237**	190	158
Sprinkler 13..18	180	**244**	**239**	**235**	172	142
Sprinkler 7..12	187	**221**	**223**	**230**	176	151
Sprinkler 1..6	154	174	183	174	153	133

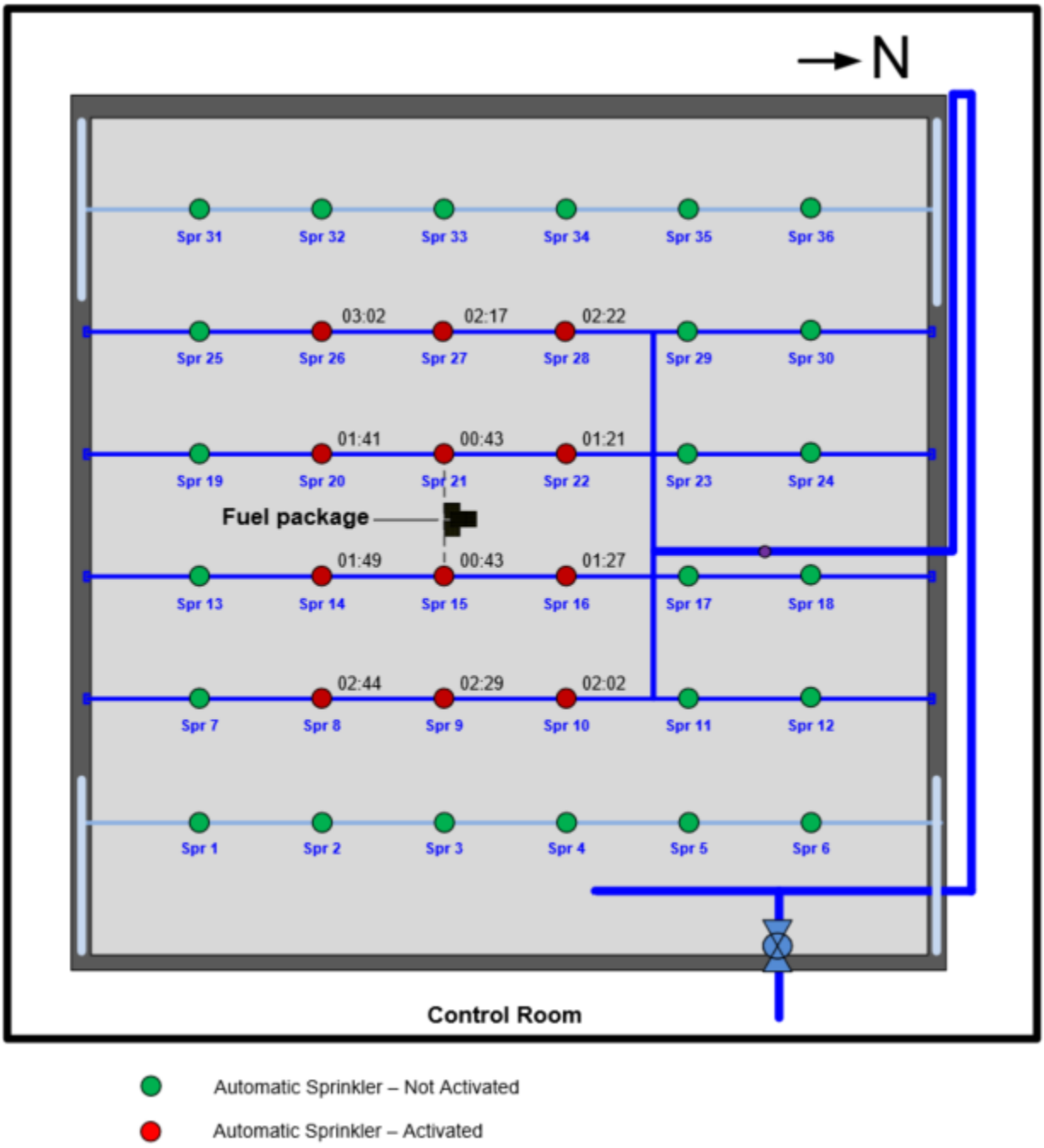


Figure 14: Test No.3 sprinkler activation diagram

Test No.4 – Water @ 24 psi

Table 20: Test No.4 sprinkler response times (mm:ss)

Sprinkler 31..36	N/A	N/A	N/A	N/A	N/A	N/A
Sprinkler 25..30	N/A	N/A	N/A	N/A	N/A	N/A
Sprinkler 19..24	N/A	N/A	**00:39**	N/A	N/A	N/A
Sprinkler 13..18	N/A	N/A	**00:45**	N/A	N/A	N/A
Sprinkler 7..12	N/A	N/A	N/A	N/A	N/A	N/A
Sprinkler 1..6	N/A	N/A	N/A	N/A	N/A	N/A

Table 21: Test No.4 maximum gas temperatures near sprinklers (°F)

Sprinkler 31..36	104	109	127	120	113	118
Sprinkler 25..30	118	129	158	149	154	126
Sprinkler 19..24	133	172	**241**	230	176	140
Sprinkler 13..18	131	176	**252**	163	151	127
Sprinkler 7..12	129	133	151	145	126	115
Sprinkler 1..6	108	118	122	118	111	106

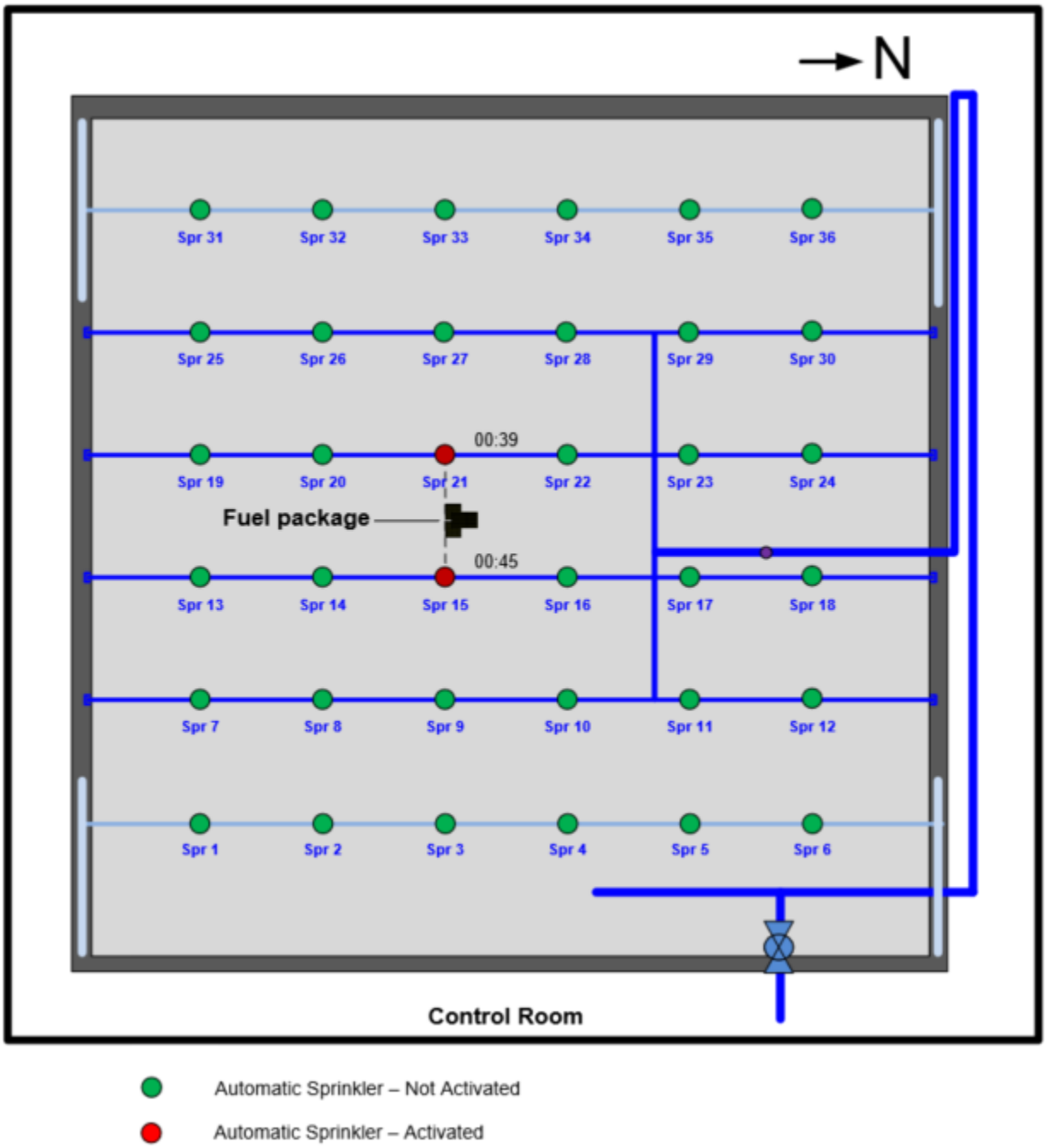


Figure 15: Test No.4 sprinkler activation diagram

Test No.5 – 50% glycerin antifreeze at 27.2 psi

Table 22: Test No.5 sprinkler response times (mm:ss)

Sprinkler 31..36	N/A	N/A	N/A	N/A	N/A	N/A
Sprinkler 25..30	N/A	N/A	N/A	N/A	N/A	N/A
Sprinkler 19..24	N/A	**01:31**	**00:41**	**01:09**	N/A	N/A
Sprinkler 13..18	N/A	**01:28**	**00:37**	**01:03**	N/A	N/A
Sprinkler 7..12	N/A	N/A	N/A	**02:57**	N/A	N/A
Sprinkler 1..6	N/A	N/A	N/A	N/A	N/A	N/A

Table 23: Test No.5 maximum gas temperatures near sprinklers (°F)

Sprinkler 31..36	144	129	154	169	138	127
Sprinkler 25..30	172	216	194	212	183	138
Sprinkler 19..24	185	**248**	**248**	**252**	189	154
Sprinkler 13..18	183	**250**	**270**	**225**	201	158
Sprinkler 7..12	154	154	214	**241**	205	151
Sprinkler 1..6	120	117	145	169	171	149

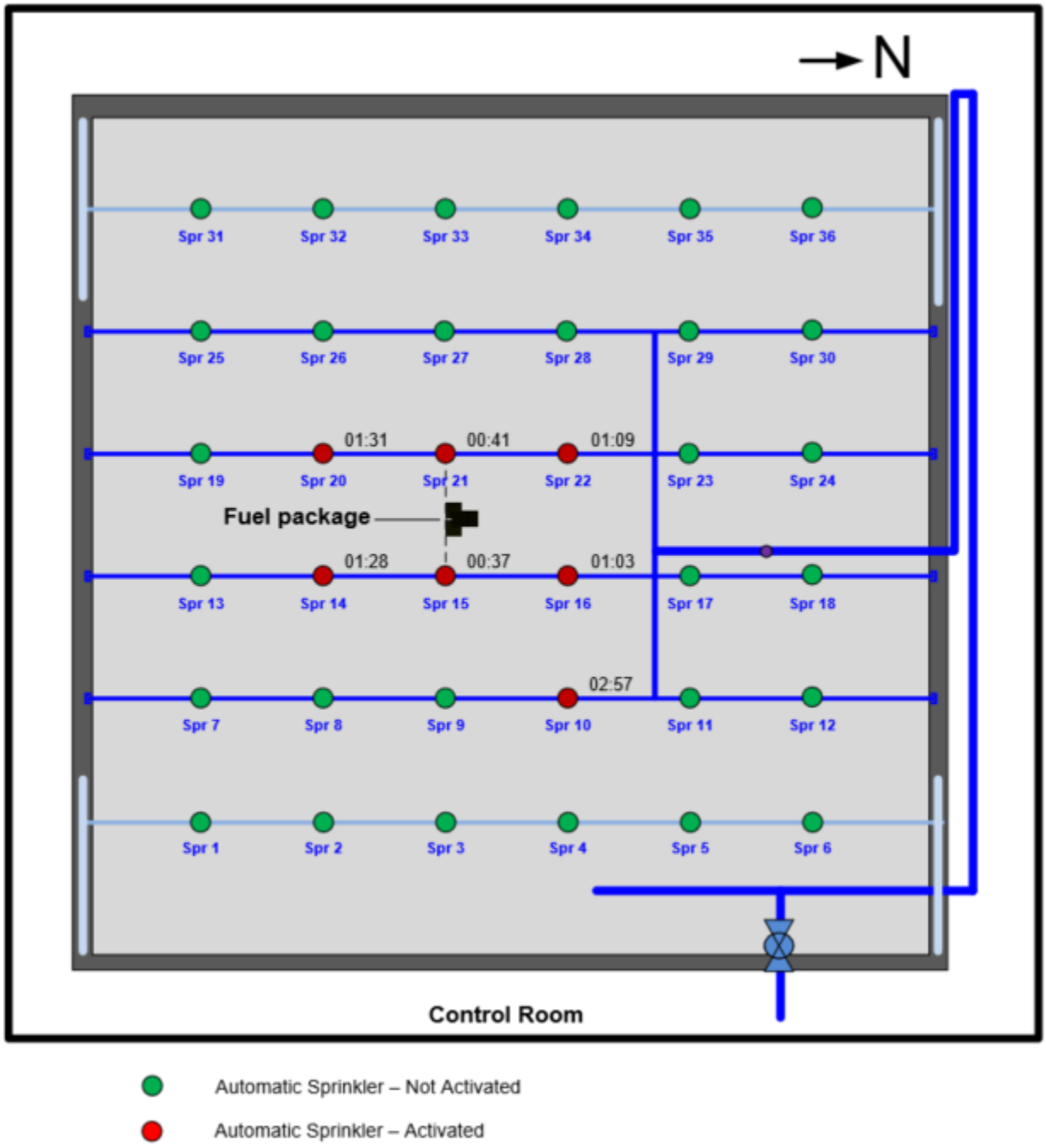


Figure 16: Test No.5 sprinkler activation diagram

Test No.6 – 38% glycerin antifreeze @ 26.4 psi

Table 24: Test No.6 sprinkler response times (mm:ss)

Sprinkler 31..36	N/A	N/A	N/A	N/A	N/A	N/A
Sprinkler 25..30	N/A	N/A	N/A	N/A	N/A	N/A
Sprinkler 19..24	N/A	N/A	**00:44**	**01:26**	N/A	N/A
Sprinkler 13..18	N/A	**01:51**	**00:48**	**02:06**	N/A	N/A
Sprinkler 7..12	N/A	N/A	N/A	N/A	N/A	N/A
Sprinkler 1..6	N/A	N/A	N/A	N/A	N/A	N/A

Table 25: Test No.6 maximum gas temperatures near sprinklers (°F)

Sprinkler 31..36	127	111	118	117	120	120
Sprinkler 25..30	151	162	151	163	163	133
Sprinkler 19..24	156	216	**243**	**257**	180	147
Sprinkler 13..18	172	**253**	**252**	**226**	183	147
Sprinkler 7..12	165	149	158	178	160	138
Sprinkler 1..6	117	122	131	126	131	124

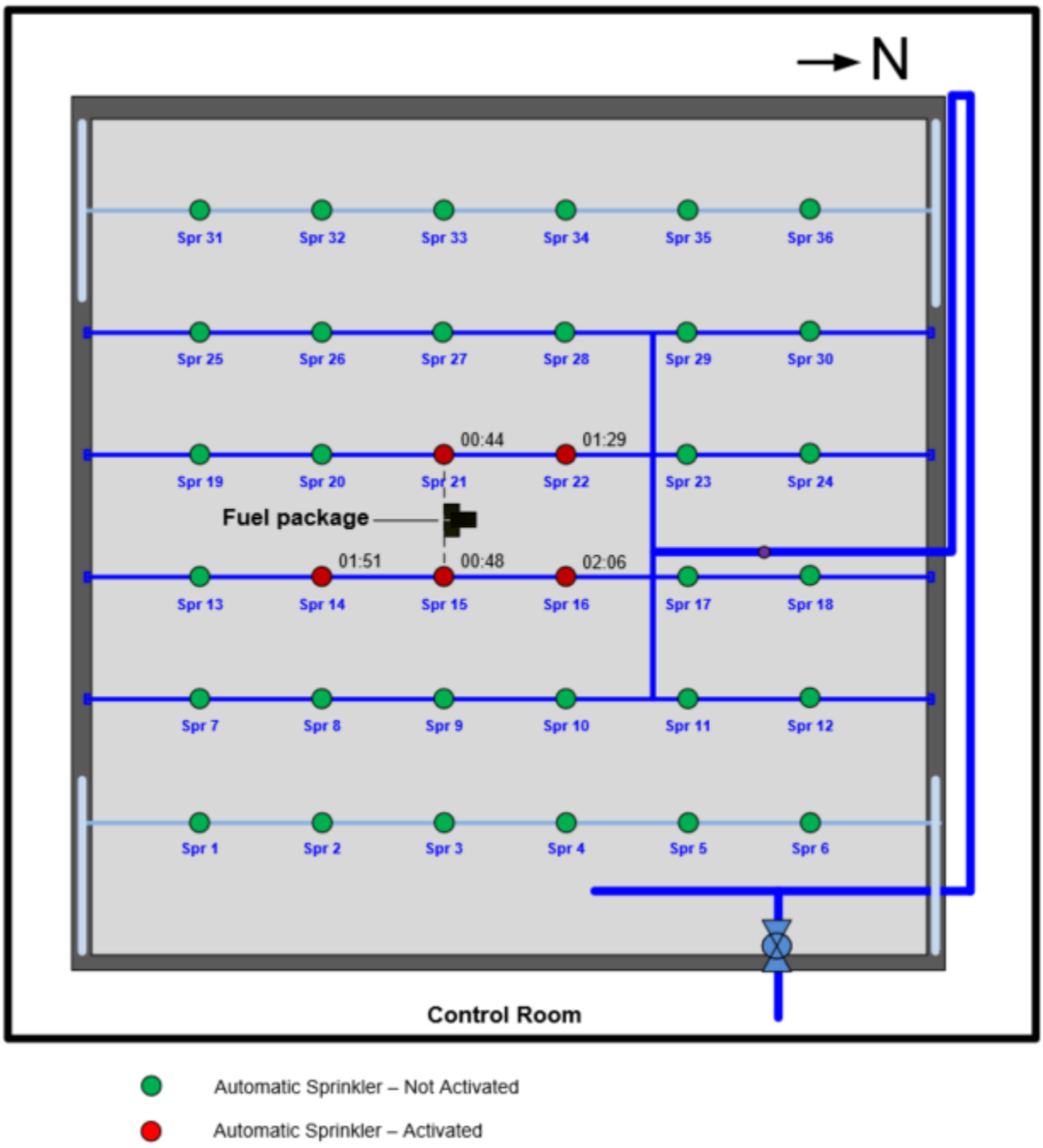


Figure 17: Test No.6 sprinkler activation diagram

Discussion

The minimum number of operating sprinklers during the light hazard fire testing was two during Test No.4 using water in a wet system and the maximum was 12 during Test No.3 using a 50 percent glycerin solution. In all cases, first sprinkler activation was within 35-45 seconds. Operated sprinklers were limited to the inner four branch lines of the sprinkler system. Test No.1 indicated that the fuel package is controlled by a UL Listed sprinkler discharging water at a discharge density consistent with the design density for light hazard occupancies referenced in NFPA 13 (0.10 gpm/ft^2). No more than the four sprinklers closest to the fuel package were activated during this test.

Table 26 gives an overview of the number of sprinklers activated as a function of discharge density and the type of fluid being discharged. In all wet system tests, the number of sprinklers activated increased as system pressure decreased and as antifreeze concentration increased. Simulation of a dry system in Test No.2 using water at 12.3 psig resulted in fewer sprinklers activated compared to the low-pressure wet system discharge of 50 percent glycerin solution at 13.9 psig (Test No.3).

The amount of cooling near ceiling level in the vicinity of the fire during each test is indicated by the average steel beam temperature and the gas temperature at 6 inches below ceiling level. Figure 18 and Figure 19 show the enhanced cooling caused by a reduction in the amount of glycerin antifreeze at a given system pressure. However, while a higher system pressure resulted in fewer sprinklers being activated (Table 26), the gas temperatures in the vicinity of the fire increased with higher pressure during tests with 50% glycerin. Figure 20 and Figure 21 show similar trends manifested in the steel beam temperatures.

Sprinkler activations summary

Table 26: Summary of total number of activated sprinklers

Discharge Density (gpm/ft^2)	**Fluid Discharged**			
	Dry System Simulation	*Water*	*38% Glycerin*	*50% Glycerin*
0.1	10	4	Not Tested	12
0.14	Not Tested	2	5	7

Note: Without fluid discharge, 21 sprinklers activated.

Temperatures 6 inches below the ceiling

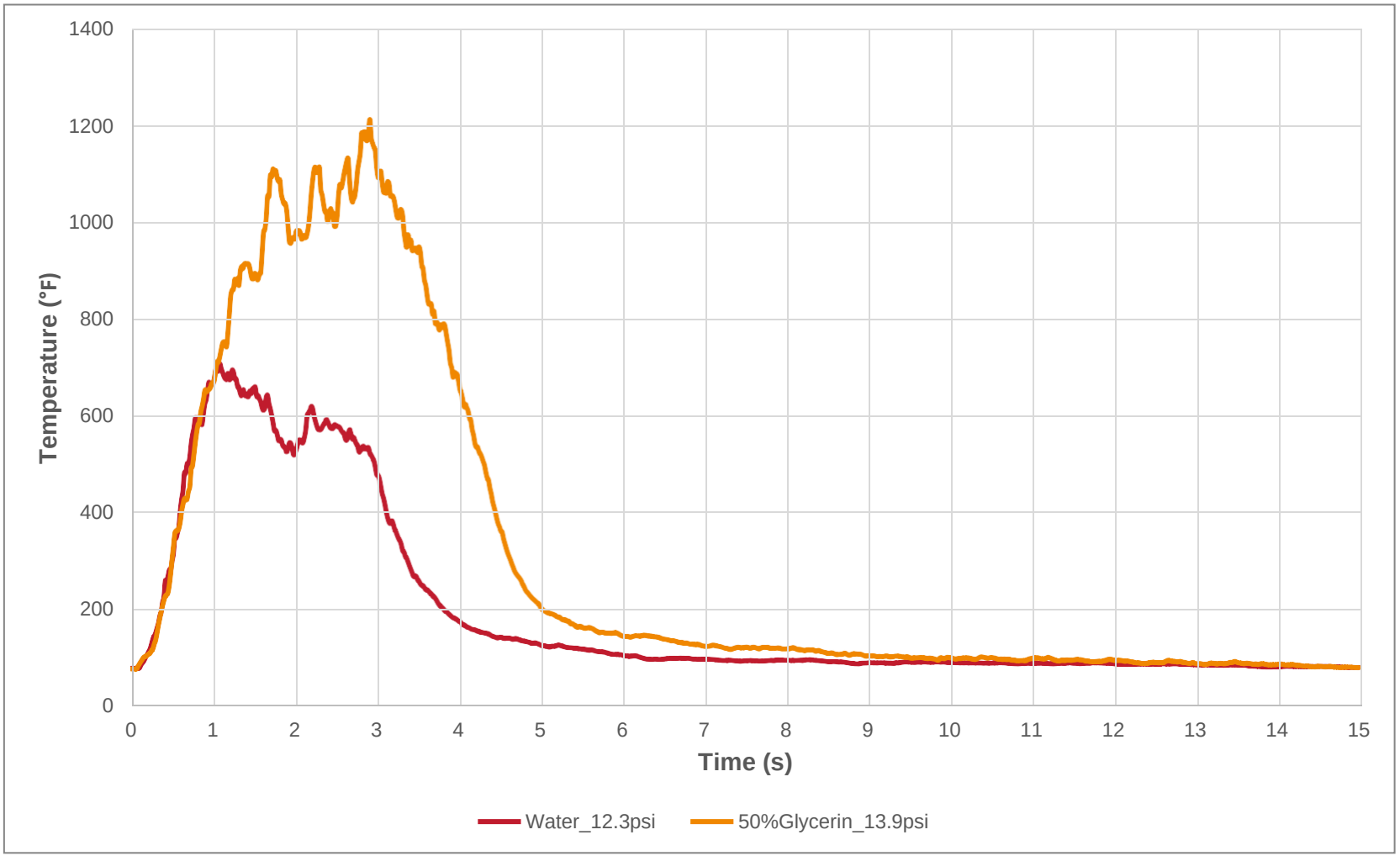


Figure 18: Temperature 6 inches below ceiling level for 0.1 gpm/ft^2 discharge density tests

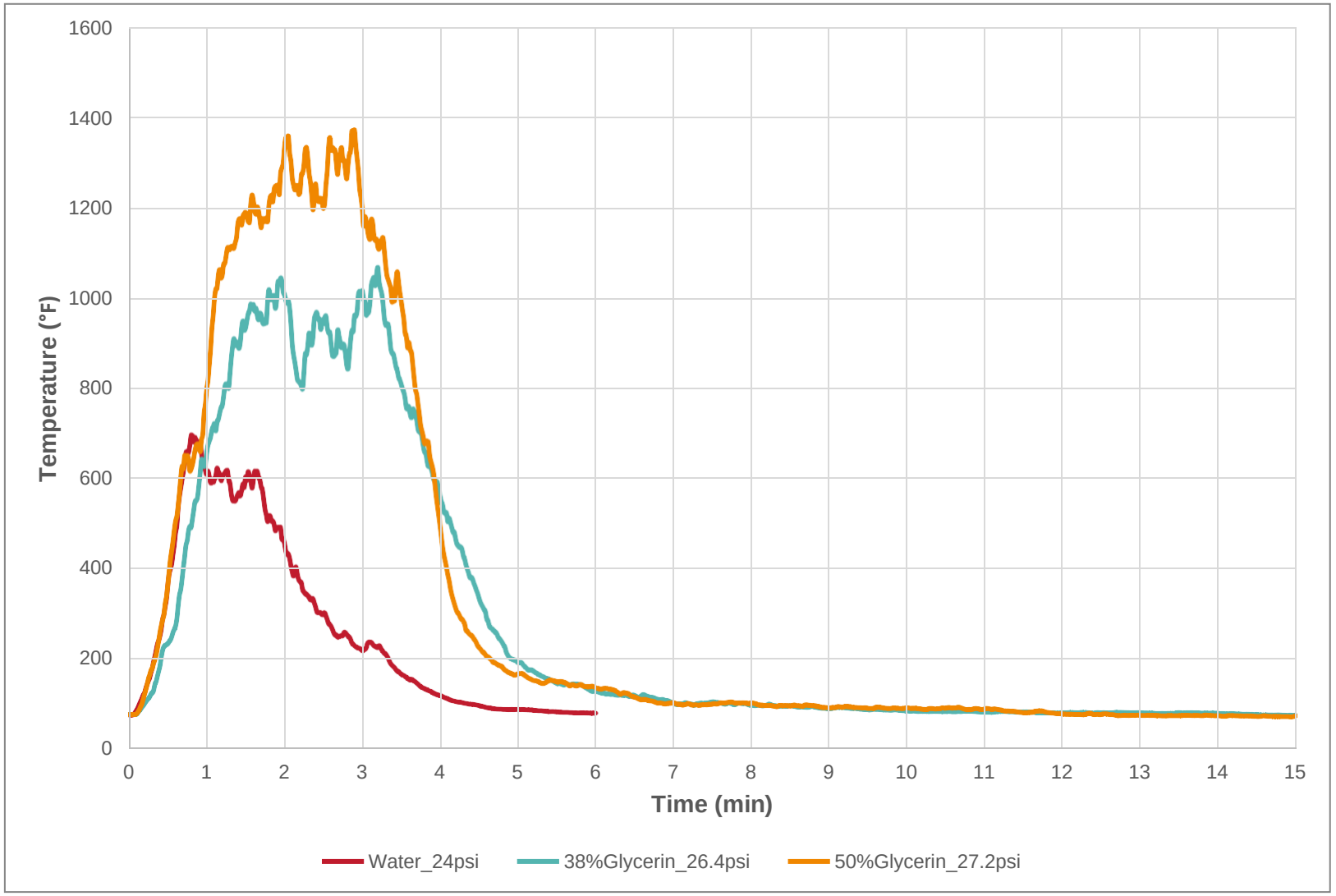


Figure 19: Temperature 6 inches below ceiling level for 0.14 gpm/ft^2 discharge density tests

Average steel beam temperatures

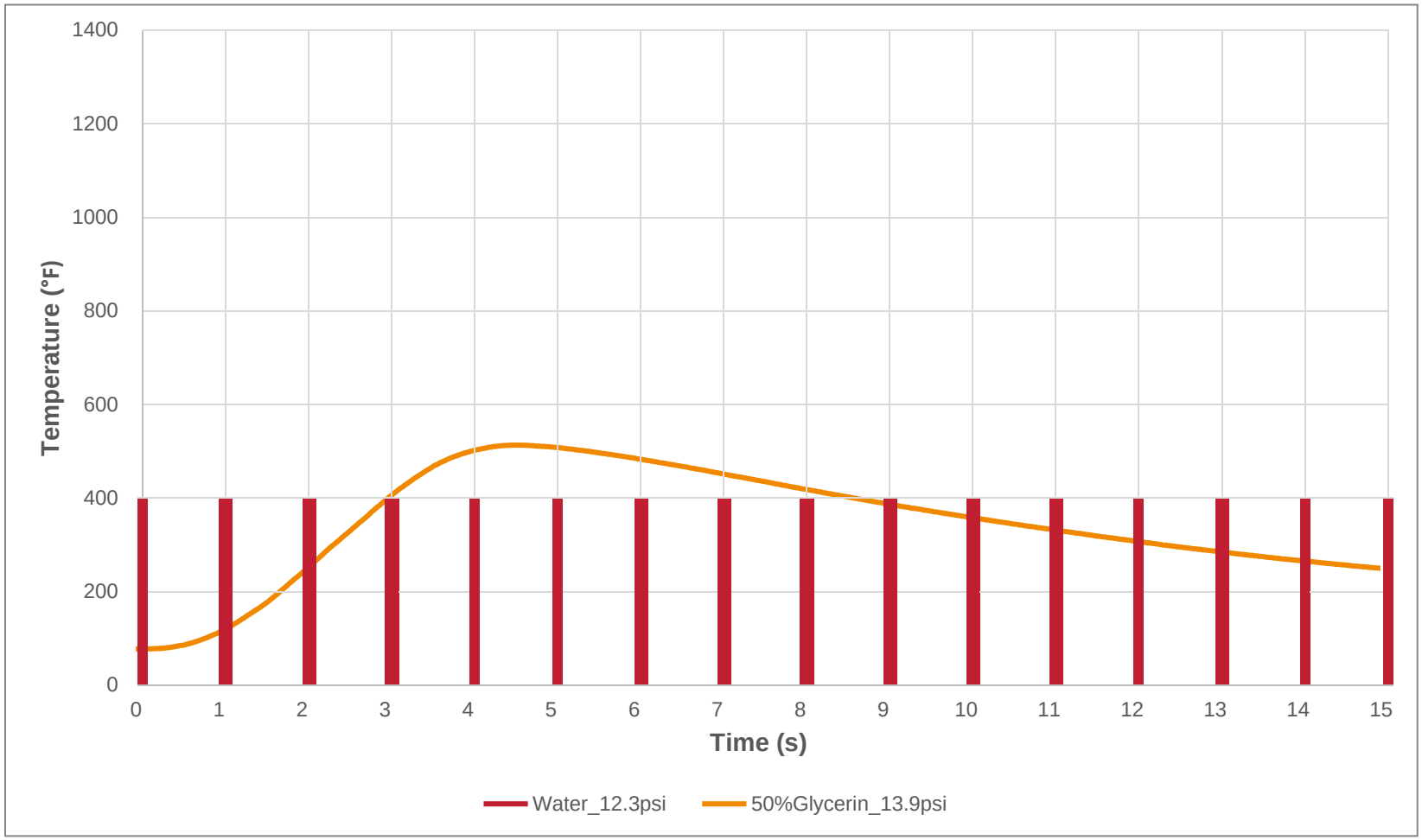


Figure 20: Average steel beam temperature for 0.1 gpm/ft^2 discharge density tests

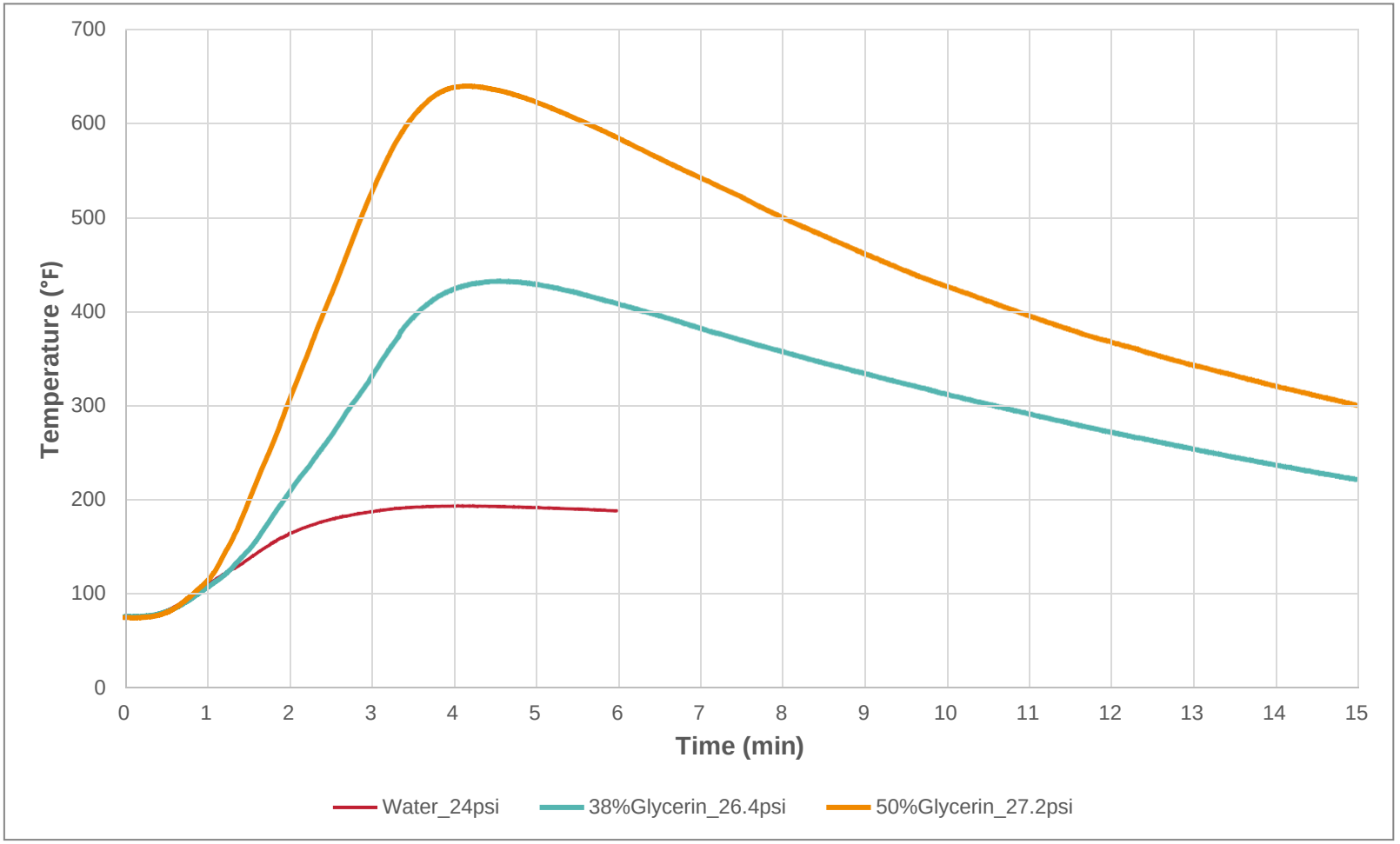


Figure 21: Average steel beam temperature for 0.14 gpm/ft^2 discharge density tests

Ordinary hazard fire testing

In addition to the light hazard occupancy testing described in the previous section, ordinary hazard occupancy fire testing was conducted with two legacy antifreeze solutions.

UL 2901 - 350 lb Wood Crib Fire Test

The fire performance of antifreeze for use in sprinkler systems protecting ordinary hazard occupancies for volumes greater than 40 gallons is currently evaluated in UL 2901 by applying the UL 199, 350 lb (159 kg) Wood Crib Fire Test. This test is typically used in UL certification of sprinklers intended for use in ordinary hazard occupancies.

The test consists of a 350 pound wood crib placed over a heptane spray burner that provides for continuous combustion of the crib. The fuel package is centered between four sprinklers. The heptane spray burner discharges heptane throughout the duration of the test. The acceptance criteria for the test is as follows:

> a) Limit the loss in weight of the wood crib to not more than 20 percent; and
>
> b) Result in the ceiling temperature reduced to a value less than 530°F (295°C) above ambient within 5 minutes after start of water discharge. Additionally, from the time the temperature initially falls below 530°F (295°C) above ambient to the end of the test, the ceiling temperature shall not exceed this value for more than three consecutive minutes and the average temperature for this period shall not exceed 530°F (295°C) above ambient. [4]

The heat release rate of the 350 pound wood crib and the heat release rate of the fuel package developed for light hazard testing are plotted in Figure 22. A photograph of the 350 lb wood crib test during discharge of 30% propylene glycol solution is shown in Figure 23.

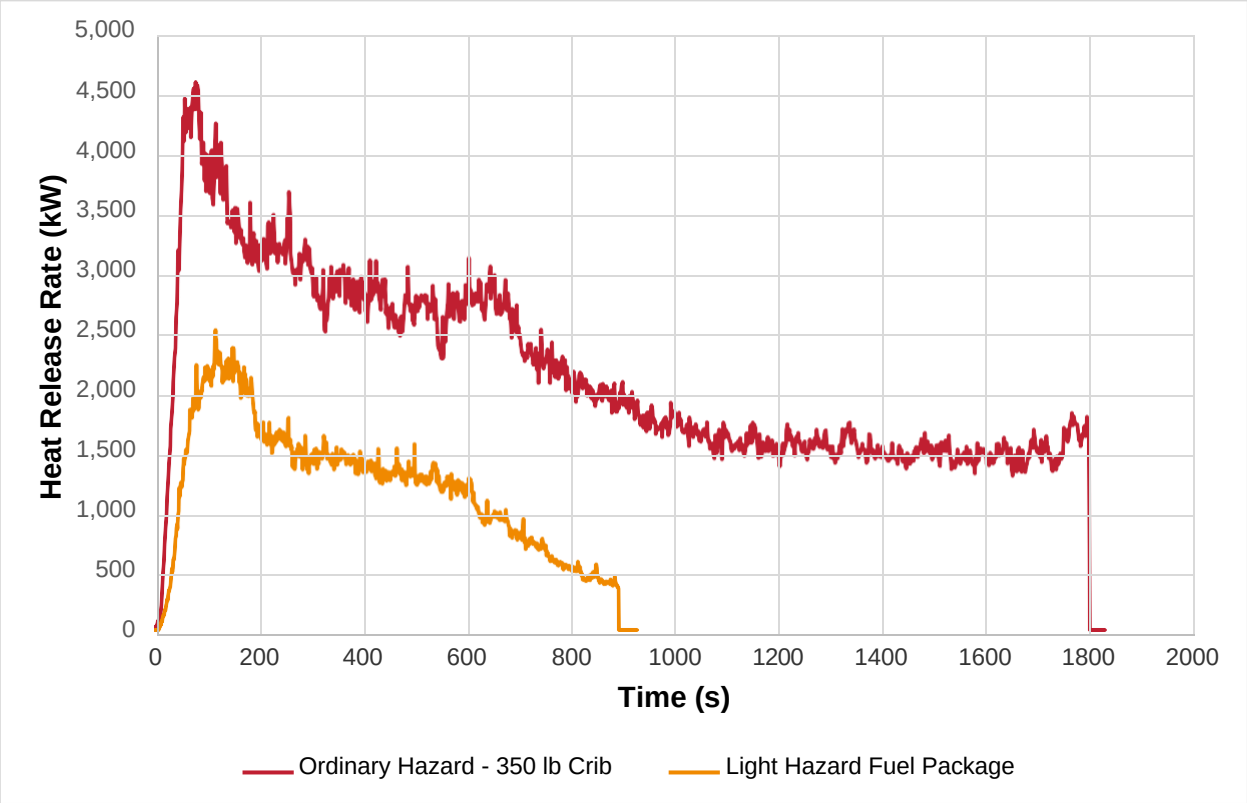


Figure 22: 350 lb wood crib and light hazard fuel package total heat release rate

Figure 23: Photo of the 350 wood crib test during discharge of 30% propylene glycol

350 Pound Wood Crib Fire Tests with traditional antifreezes

Three 350 lb Wood Crib Fire Tests were conducted discharging (1) a 38% glycerin solution, (2) a 30% propylene glycol solution and (3) water only. The testing was conducted with nominal K5.6, standard coverage upright spray sprinklers. The sprinklers were open, spaced 10-foot by 10-foot, flowing 15 gpm per sprinkler in accordance with UL 199. The ceiling temperature measured above the fire for each test is plotted in Figure 24. While discharging the antifreeze solutions, there was a relatively small decrease in the gas ceiling temperatures measured above the fire. It was only after water began flowing that the ceiling temperatures began to drop significantly.

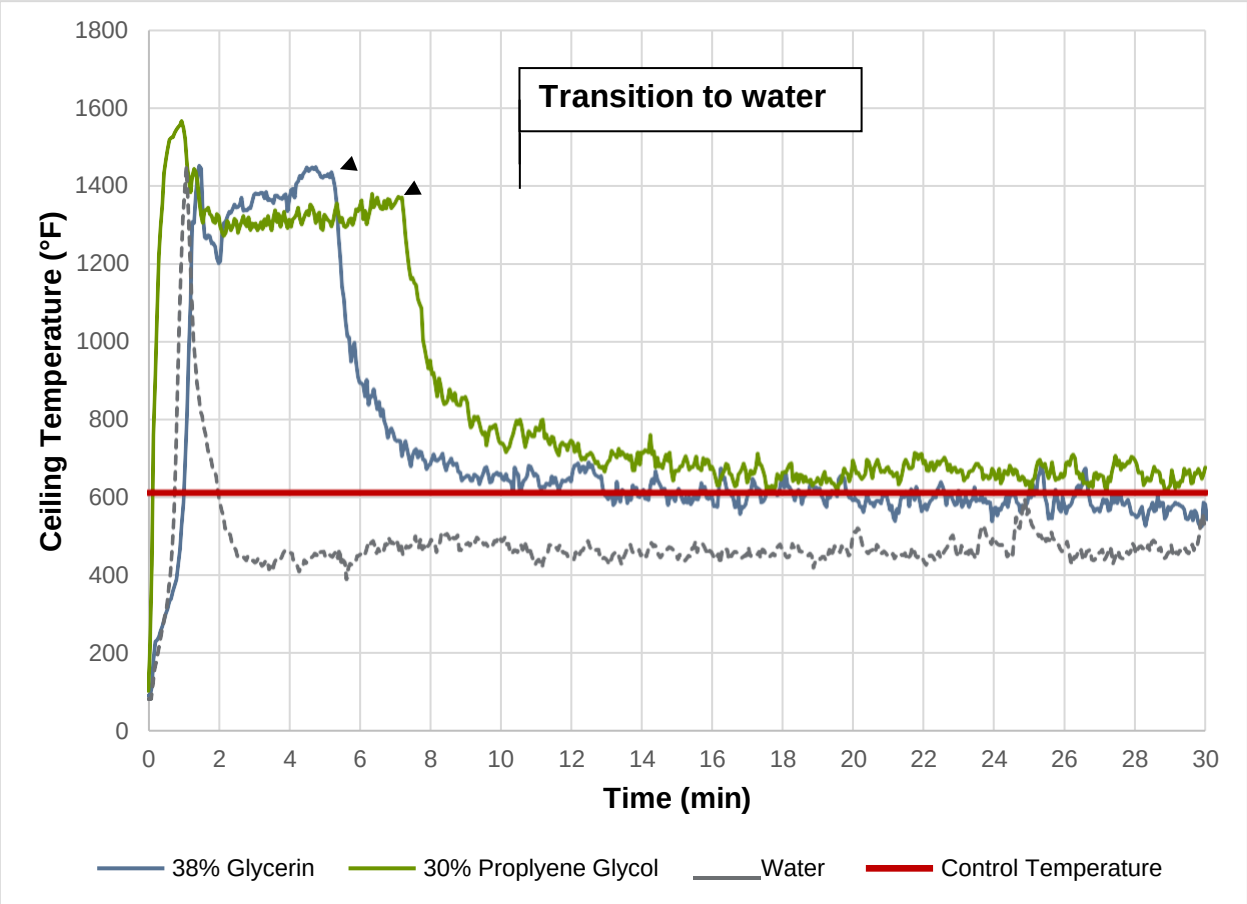


Figure 24: Ceiling Temperature from the UL 199, 350 lb Wood Crib Fire Test with 38 % glycerin, 30% propylene glycol and water

Summary

The series of tests demonstrated differences in performance between concentrations and types of antifreeze solutions as compared to water at the same discharge densities. In general, the following observations were made based on the data contained in this report:

- The ceiling temperatures during the light hazard fire testing with antifreeze solutions were higher and the number of operating sprinklers was greater as compared to water.

- The ceiling temperatures during the ordinary hazard fire testing with antifreeze solutions did not significantly decrease until the transition from antifreeze to water occurred during the test.

The results from the tests imply that the antifreeze solution concentration and fire size impact the performance as compared to water. As the concentration of the antifreeze solution increases or as the fire size increases, the difference in performance is greater.

A total of six tests were conducted using the light hazard fuel package located between two sprinklers on separate branch lines.

Three tests were conducted using a nominal sprinkler discharge density of 0.10 gpm/ft^2 for the duration of the test, which correlated to a discharge pressure of 12.3 psig for water. One test was conducted using water as a wet system, one test was conducted using water as a simulated dry system, and one test was conducted with 500 gallons of a 50 percent (by volume) glycerin antifreeze solution followed by water. During the test using water in a wet system, a total of 4 sprinklers operated compared to 12 sprinklers that operated during the test using the glycerin solution followed by water. The number of operated sprinklers for the 50 percent glycerin solution exceeded the UL certification acceptance criteria, which is a maximum of 10 sprinklers using this test pressure. During the simulated dry system testing with water, a total of 10 sprinklers operated.

Three tests were conducted using a higher sprinkler discharge pressure, based on a nominal 24 psig discharge pressure for water, to simulate a higher starting pressure for a sprinkler system that was hydraulically designed for a 0.10 gpm/ft^2 discharge density. One test was conducted with water, one test was conducted with approximately 500 gallons of a 50 percent glycerin antifreeze solution followed by water and one test was conducted with 500 gallons of a 38 percent glycerin antifreeze solution followed by water. During the test using water, a total of 2 sprinklers operated compared to 7 sprinklers that operated during the test using the 50 percent glycerin and 5 sprinklers that operated during the test using the 38 percent glycerin solution. The number of operated sprinklers for both the 50 and 38 percent glycerin solutions exceeded the UL certification acceptance criteria of 4 sprinklers.

For ordinary hazard occupancy applications using an antifreeze solution volume greater than 40 gallons, UL 2901 requires fire testing using a fuel package described in UL 199. Three tests were conducted; one using water, one using 38 percent glycerin antifreeze solution followed by water and one test using a 30 percent propylene glycol antifreeze solution followed by water. During the test using water, the ceiling temperature was reduced to below 600 °F after 5 minutes of water discharge compared to approximately 1,450°F for the glycerin solution and 1350°F for the propylene glycol solution prior to being followed with water. Currently, there are no antifreeze solutions that are UL Listed for ordinary hazard occupancy applications with a volume greater than 40 gallons.

For all tests with the antifreeze solutions, the test pressure was adjusted for the density of the solution to maintain the desired discharge density. A description of the test parameters and results for the light hazard type tests is provided in Table 1 (English units) and Table 2 (Metric units). A graphical presentation of the ceiling temperatures for the ordinary hazard type fire tests are described in Figure 24.

Currently, UL 2901 describes three types of fire tests as follows:

- Exposure to Fire (evaluates the antifreeze solution for resistance to ignition and substantial contribution to the fire)
- Fire Fighting Effectiveness - Residential Dwelling Units
- Fire Fighting Effectiveness -- Ordinary Hazard Occupancies, UL 199 - 350 lb Wood Crib Fire Test for sprinkler systems with volumes greater than 40 gallons.

Tables 27-29 summarize the results of the fire testing that has been conducted on the legacy NFPA 13 glycerin and propylene glycol antifreeze solutions using the UL 2901 fire tests and the light hazard fire test described herein as compared the acceptance criteria that is required for UL Listing.

Table 27: Summary of UL's antifreeze research — Exposure to fire

Test	UL Acceptance Criteria Listed Antifreeze Solutions	Test Details	Test Results			
			38% Glycerin	50% Glycerin	30% Propylene Glycol	40% Propylene Glycol
Exposure to Fire (Evaluates the resistance to ignition and substantial contribution to the fire)	Not more than a 40 percent increase above the maximum running 15 s average total heat release rate for the nominal 3,000 kW base fire	Test 1 - Nominal K=4.2 SSP 8 ft. ceiling	Compliant – 24.0% increase	Noncompliant- 84.1 % increase	Compliant - 18.4% increase	Not tested – Assumed Noncompliant based upon 50% glycerin test results
		Test 2 - Nominal K=4.2 SSP 20 ft. ceiling	Compliant - 26.9% increase	Noncompliant- >230%* increase	Compliant - 8.5% increase	Not tested – Assumed Noncompliant based upon 50% glycerin test results
		Test 3 - Nominal K=8.0 SSP 8 ft. ceiling	Compliant - 24.1% increase	Compliant- 28.6 % increase	Compliant - 12.9% increase	Not tested – Assumed Compliant based upon 50% glycerin test results
		Test 4 - Nominal K=8.0 SSP 20 ft. ceiling	Compliant - 13.7% increase	Noncompliant - >230%* increase	Compliant - 13.8% increase	Not tested – Assumed Noncompliant based upon 50% glycerin test results

*The calorimeter is calibrated to a maximum of 10 MW, an increase of 230% over the nominal 3MW base line fire.

Table 28: Summary of UL's antifreeze research — Residential and light hazard

Test	UL Acceptance Criteria Listed Antifreeze Solutions	Test Details	Test Results			
			38% Glycerin	50% Glycerin	30% Propylene Glycol	40% Propylene Glycol
Fire Fighting Effectiveness - Residential Dwelling Units	Temperature acceptance criteria and not more than 2 operated sprinklers	Test 1 – Nominal K=4.9 Pendent Residential Sprinkler, Low Flow	Compliant based upon 50% test results	Compliant	Compliant based upon 40% test results	Compliant
		Test 2 – Nominal K=4.9 Pendent Residential Sprinkler, 100 psig	Compliant based upon 50% test results	Compliant at 80 and 150 psig	Not Tested - Assumed Compliant based upon glycerin test results	Not Tested - Assumed Compliant based upon glycerin test results
		Test 3 – Nominal K=4.2 Sidewall Residential Sprinkler, Low Flow	Compliant based upon 50% test results	Compliant	Not Tested - Assumed Compliant based upon glycerin test results	Not Tested - Assumed Compliant based upon glycerin test results
		Test 4 – Nominal K=4.2 Sidewall Residential Sprinkler, 100 psig	Compliant based upon 50% test results	Compliant at 80 and 150 psig	Not Tested - Assumed Compliant based upon glycerin test results	Not Tested - Assumed Compliant based upon glycerin test results
Fire Fighting Effectiveness - Light Hazard Occupancies	Not more than 10 operated sprinklers	Test 1 - Nominal 5.6 SSU Sprinklers, 14 ft. by 14 ft. spacing, 12.3 psig, 175 °F Temperature Rating	Not tested	Noncompliant - 12 Operated Sprinklers	Not Tested	Not Tested
	Not more than 4 operated sprinklers	Test 2 - Nominal 5.6 SSU Sprinklers, 14 ft. by 14 ft. spacing, 24 psig, 175 °F Temperature Rating	Noncompliant - 5 Operated Sprinklers	Noncompliant - 7 Operated Sprinklers	Not Tested	Not Tested

Table 29: Summary of UL's antifreeze research — Ordinary hazard

Test	UL Acceptance Criteria Listed Antifreeze Solutions	Test Details	38% Glycerin	50% Glycerin	30% Propylene Glycol	40% Propylene Glycol
Fire Fighting Effectiveness -- Ordinary Hazard Occupancies, UL 199 350 lb Wood Crib Fire Test for Sprinklers for greater than 40 gallons[1]	Gas ceiling temperature above fire to be reduced to below 530 °F plus ambient temperature	Single test with four open, nominal 5.6 SSP sprinkler installed on 10 ft by 10 ft. spacing, 15 gpm/sprinkler	Noncompliant- 1462 °F Versus 622 °F Control Temperature	Not Tested – Assumed Noncompliant based upon 38% test results	Noncompliant - 1380 °F Versus 632 °F Control Temperature	Not Tested – Assumed Noncompliant based upon 30% test results

Note 1: At the time of publication of this report, there were no listed antifreeze solutions for ordinary hazard occupancies for volumes greater than 40 gallons

References

1. National Fire Protection Association. (2020). NFPA 25, Standard for the Inspection, Testing, and Maintenance of Water-Base Fire Protection Systems

2. National Fire Protection Association. (2019). NFPA 13, Standard for the Installation of Sprinkler Systems.

3. Underwriters Laboratories Inc. (2020). Standard for Safety for Antifreeze Solutions for Use in Fire Protection Systems, UL 2901.

4. Underwriters Laboratories Inc. (2020). Standard for Safety for Automatic Sprinklers for Fire-Protection Service, UL 199.

5. Antifreeze Systems in Home Fire Sprinkler Systems — Literature Review and Research Plan, Fire Protection Research Foundation, June 2010.

6. Antifreeze Systems in Home Fire Sprinkler Systems — Phase II Final Report, Fire Protection Research Foundation, December 2010.

7. Antifreeze Solutions Supplied through Spray Sprinklers — Final Report, Fire Protection Research Foundation, November 2012.

8. Madrzykowski, D., and Vettori, R. L., Sprinkler Fire Suppression Algorithm for the GSA Engineering Fire Assessment System (NISTIR 4833), Natl. Inst. Stand. Technol., Gaithersburg, MD (1992).

9. Madrzykowski, D., Office Work Station Heat Release Rate Study: Full Scale vs. Bench Scale, pp. 47-55 in Interflam ‘96, Interscience Communications Ltd., London (1996).

10. Kakegawa, S., et al., Design Fires for Means of Egress in Office Buildings Based on Full-scale Fire Experiments, pp. 975-986 in *Fire Safety Science—Proc. 7th Intl. Symp.,* International Association for Fire Safety Science (2003).

11. Madrzykowski, D., and Walton, W. D. Cook County Administration Building Fire, 69 West Washington, Chicago, Illinois, October 17, 2003: Heat Release Rate Experiments and FDS Simulations (NIST SP 1021), Nat. Inst. Stand. & Technol., Gaithersburg MD (2004).

Appendix A: Example test video frames (Test No.3)

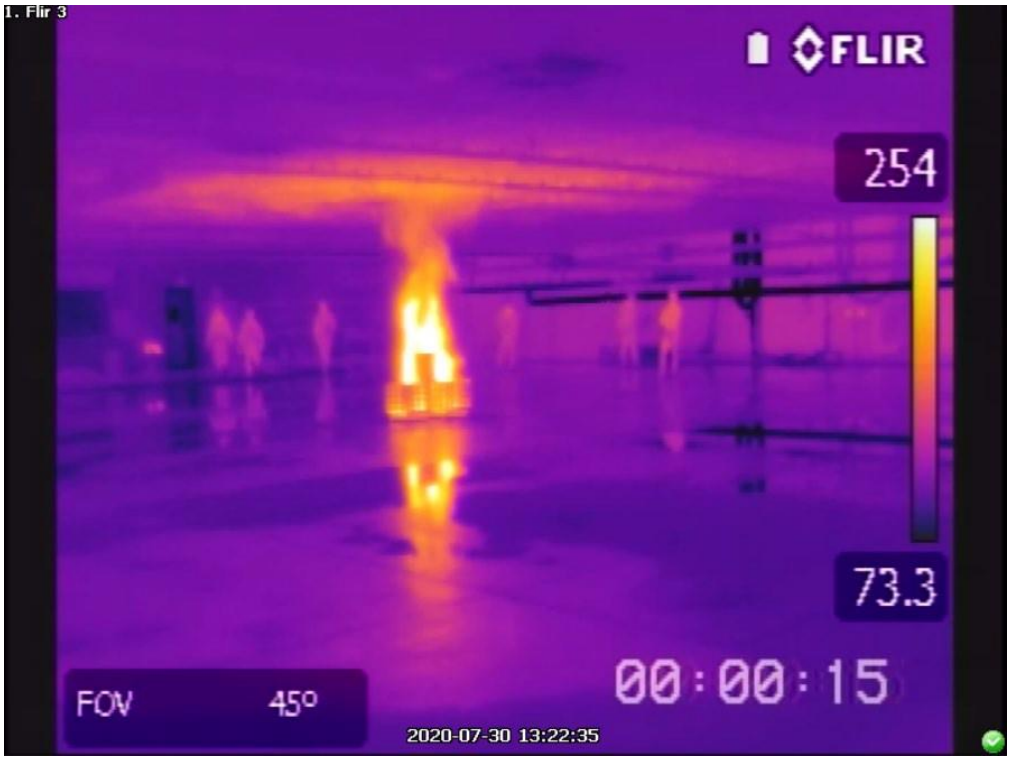


Figure 25: Test frame 1 (00:15)

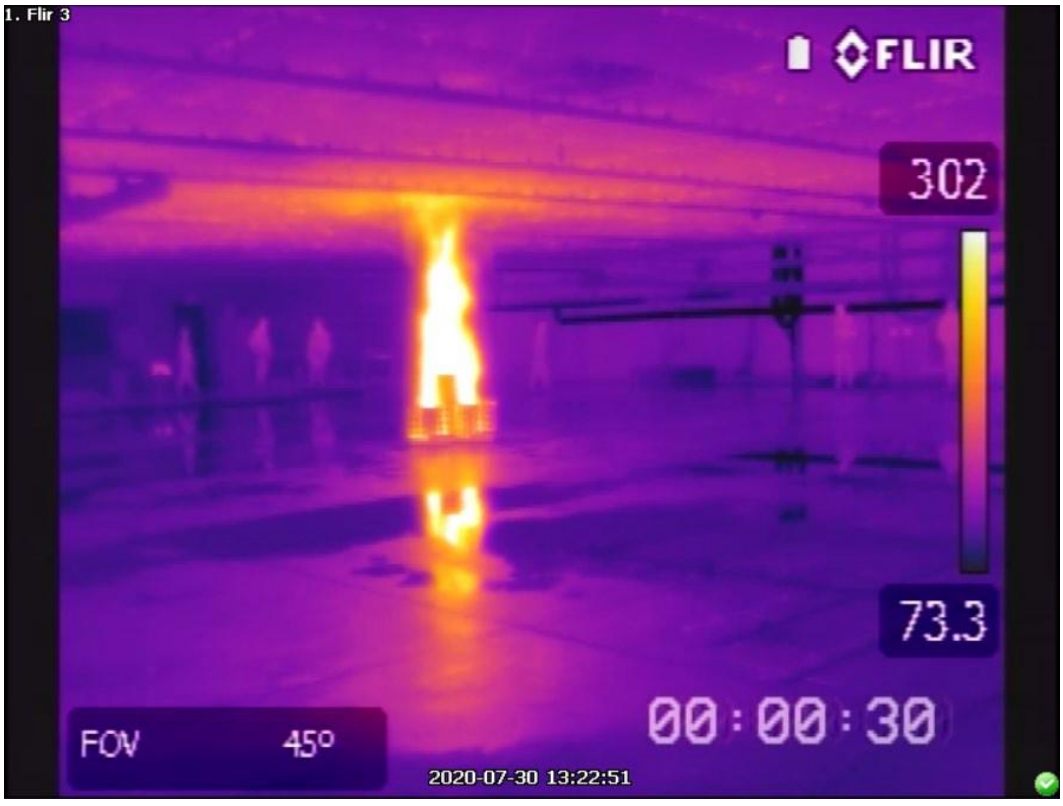


Figure 26: Test frame 2 (00:30)

Figure 27: Test frame 3 (01:00)

Figure 28: Test frame 4 (03:00)

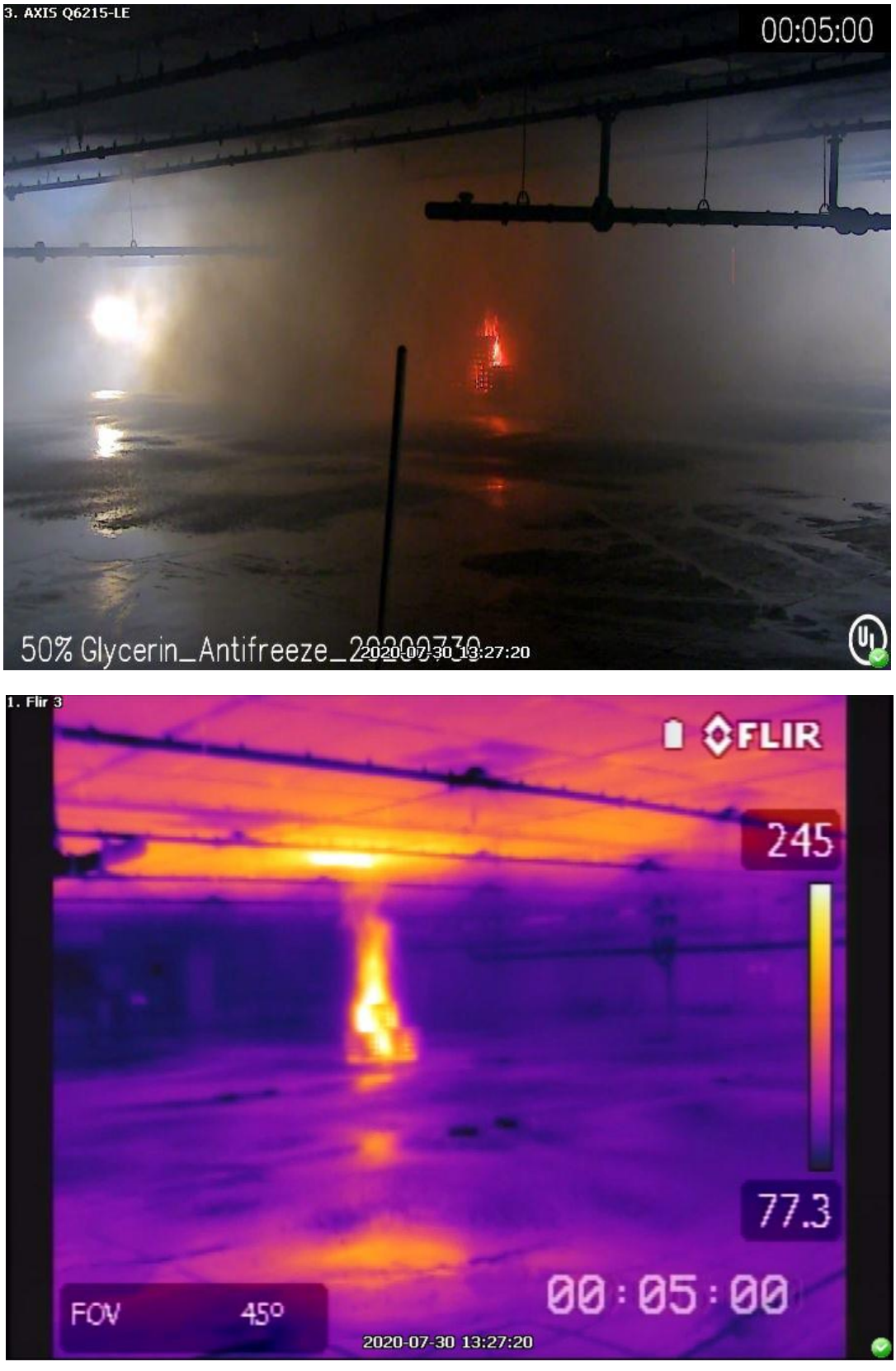


Figure 29: Test frame 5 (05:00)

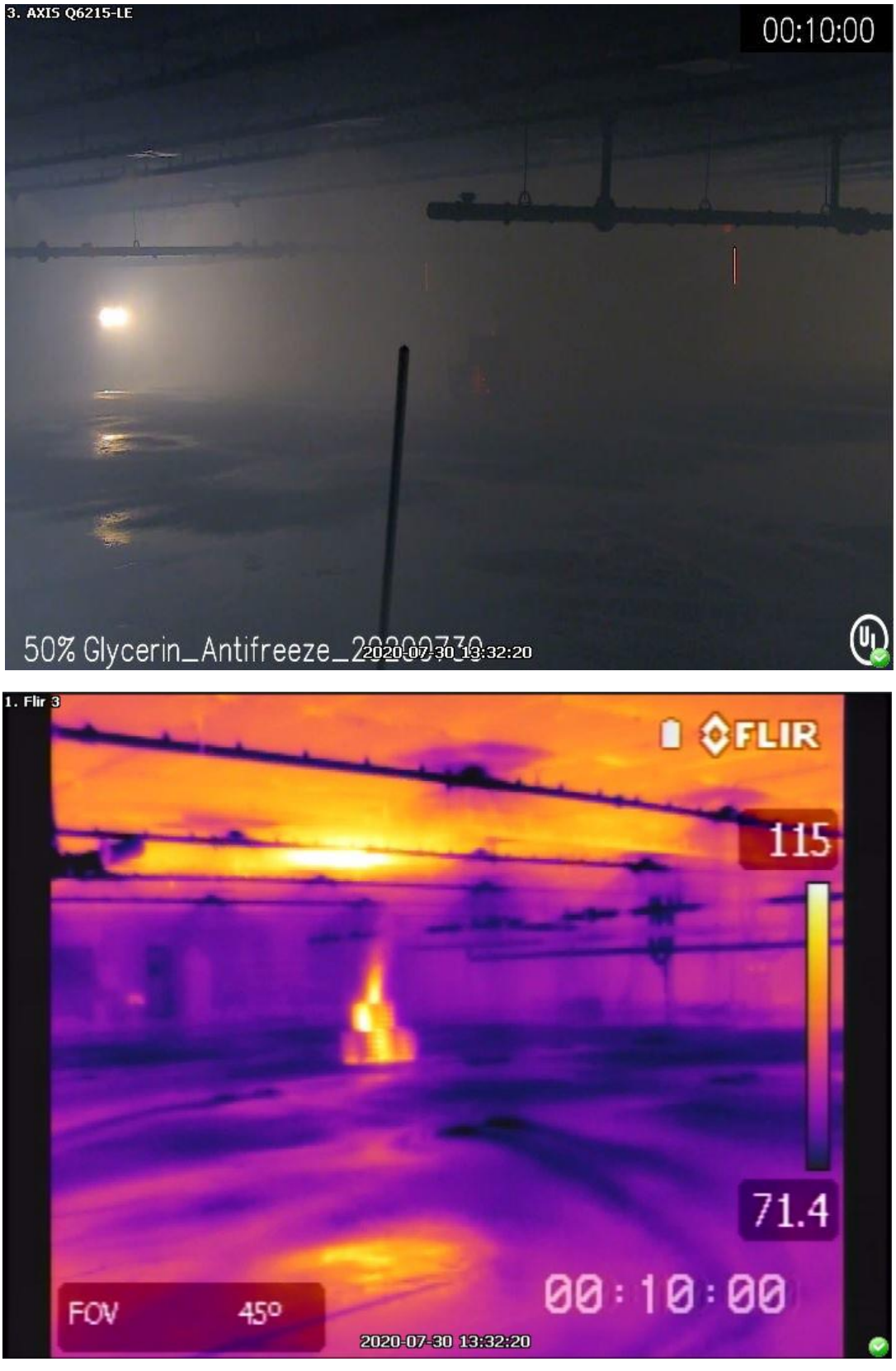


Figure 30: Test frame 6 (10:00)

Figure 31: Test frame (15:40 , 40 seconds post-test)

Appendix B: Light hazard testing sprinkler temperature plots by branch line

This appendix presents temperature data collected by the thermocouples mounted near each sprinkler. Data is plotted per branch line. Sharp temperature drops indicate sprinkler activation.

Test No.1 – Water @ 12.3 psi

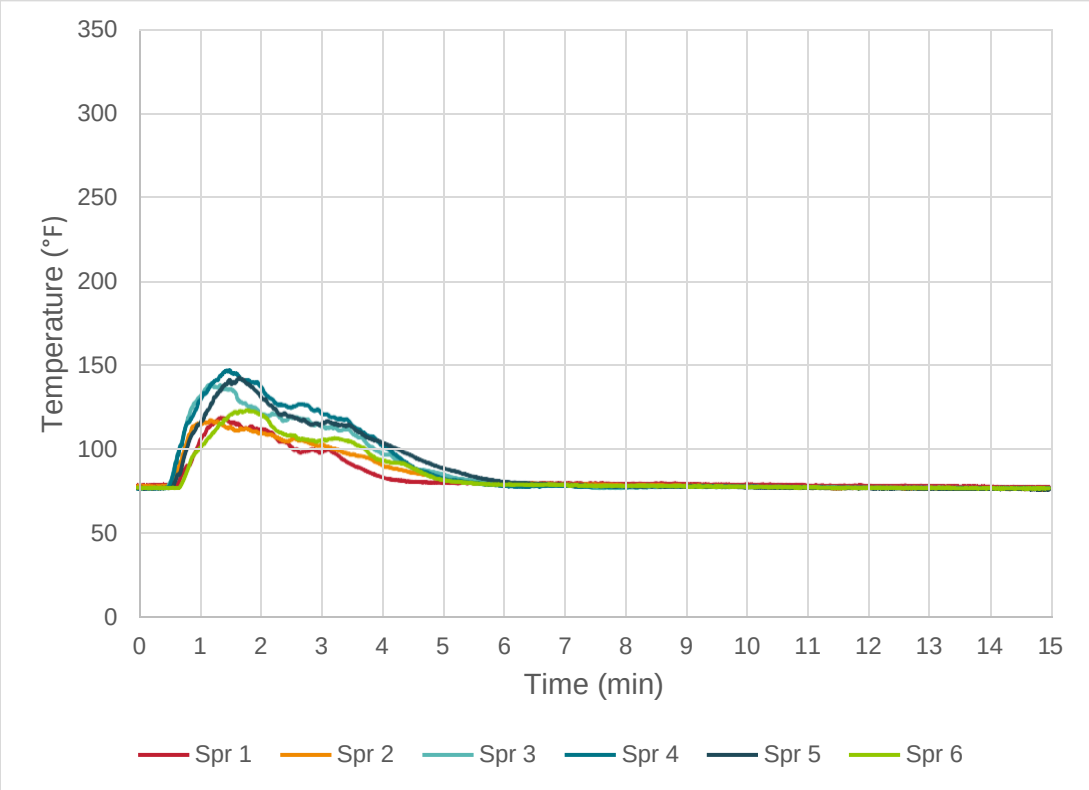


Figure 32: Test No.1 branch line 1 (Sprinklers 1-6) temperatures

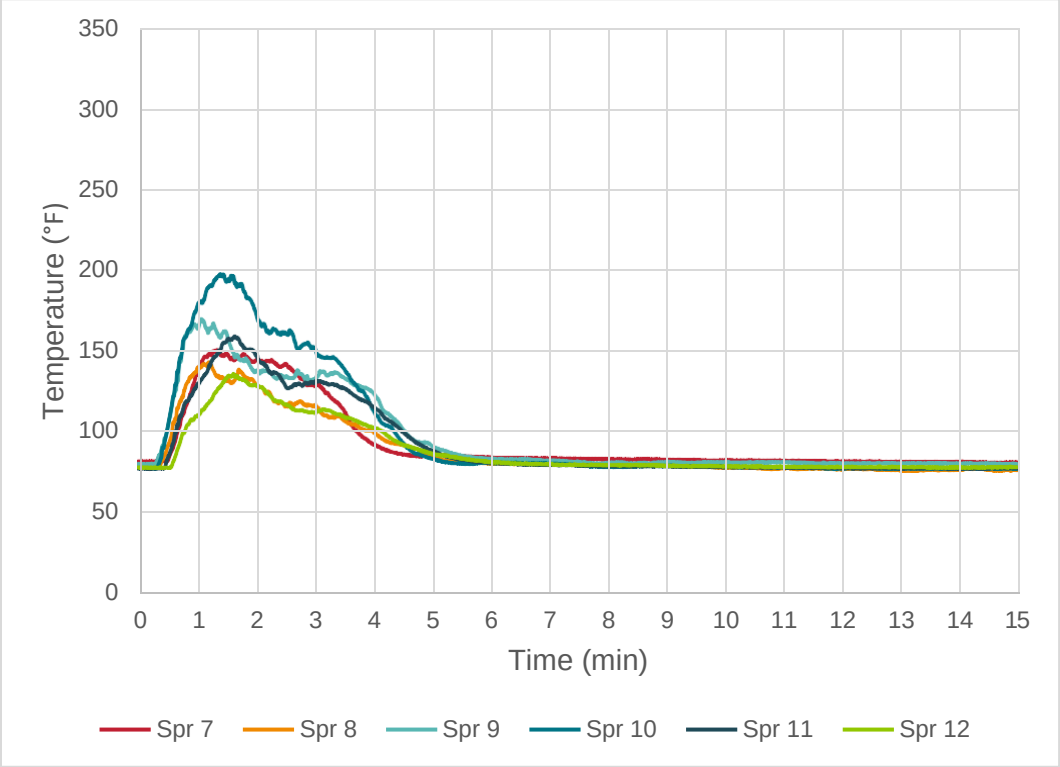


Figure 33: Test No.1 branch line 2 (Sprinklers 7-12) temperatures

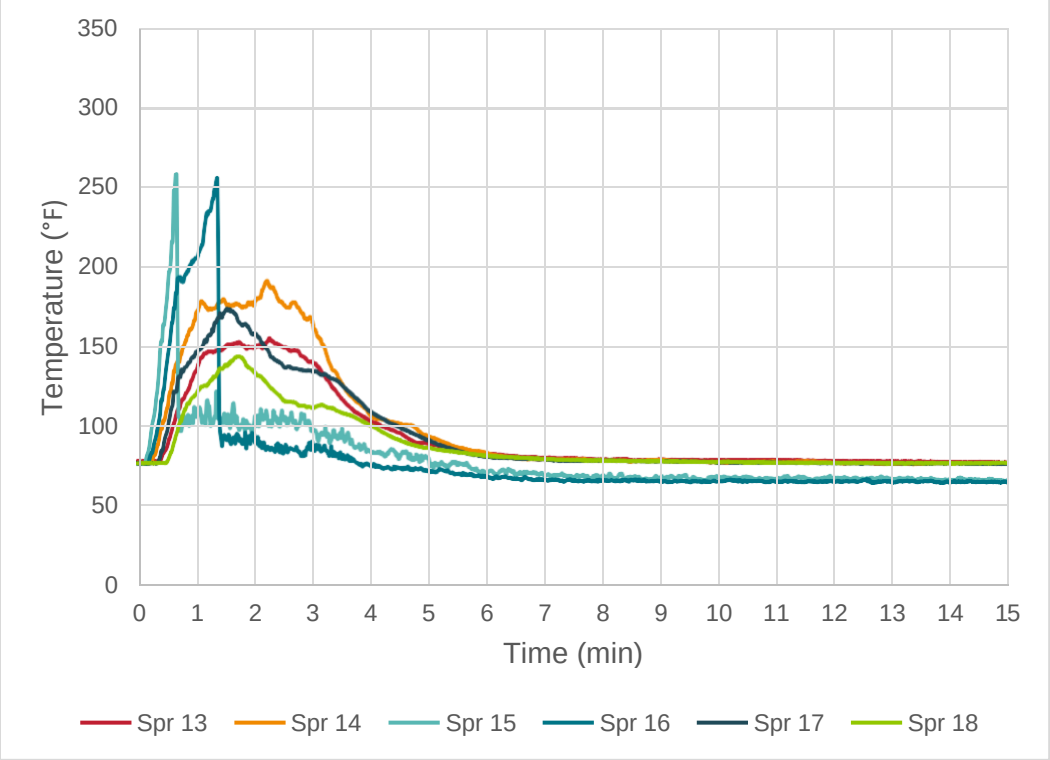


Figure 34: Test No.1 branch line 3 (Sprinklers 13-18) temperatures

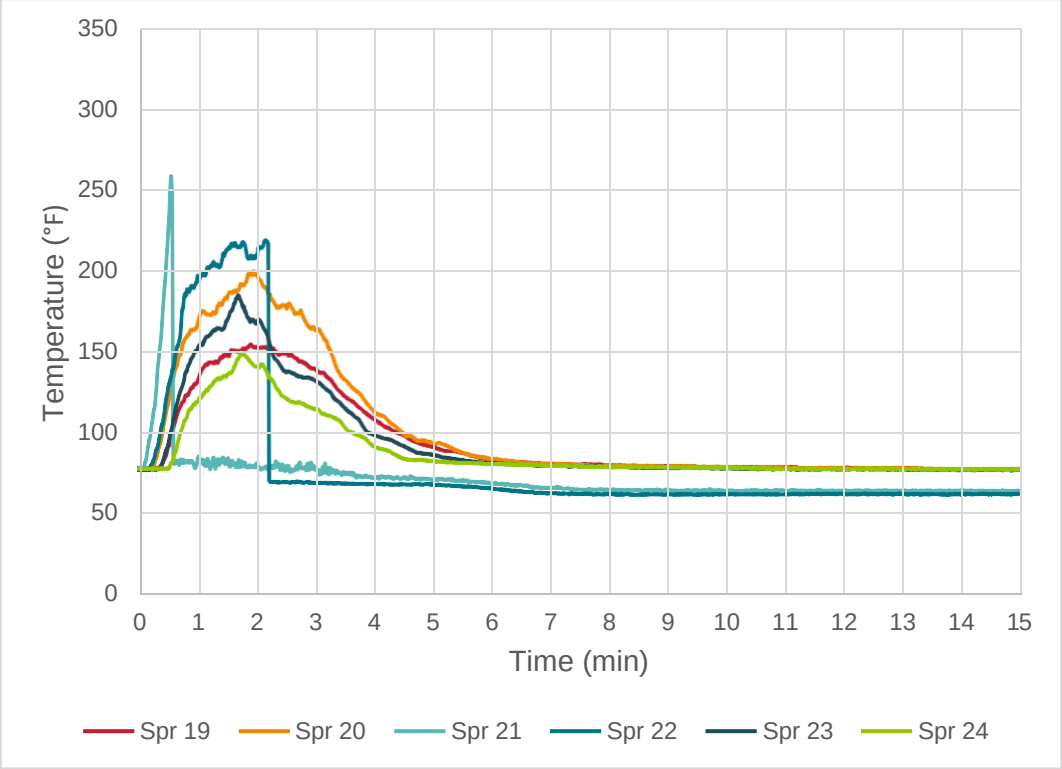


Figure 35: Test No.1 branch line 4 (Sprinklers 19-24) temperatures

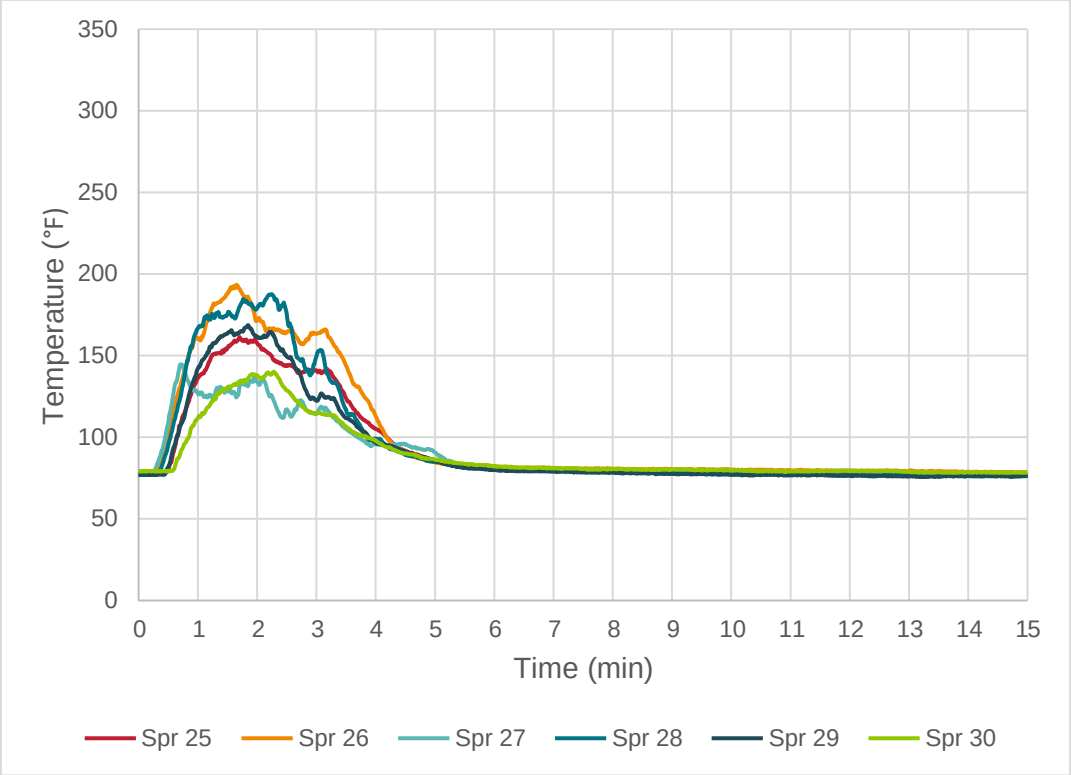


Figure 36: Test No.1 branch line 5 (Sprinklers 25-30) temperatures

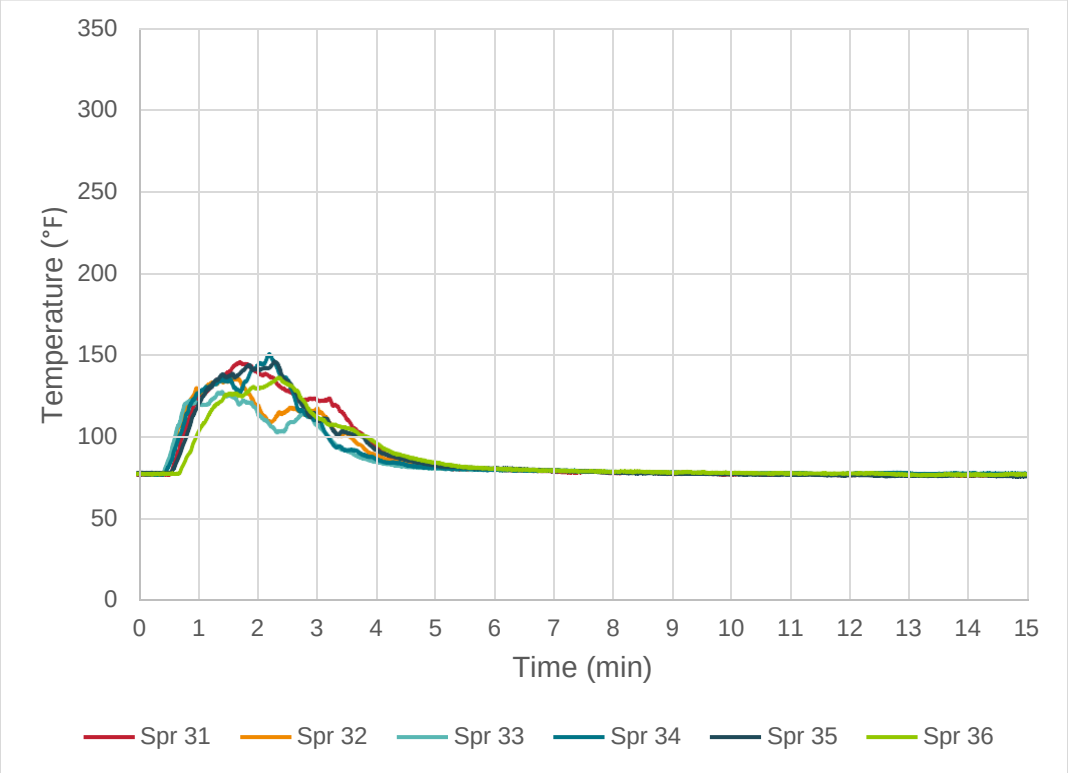


Figure 37: Test No.1 branch line 6 (Sprinklers 30-36) temperatures

Test No.2 – Dry system simulation with water @ 12.3 psi

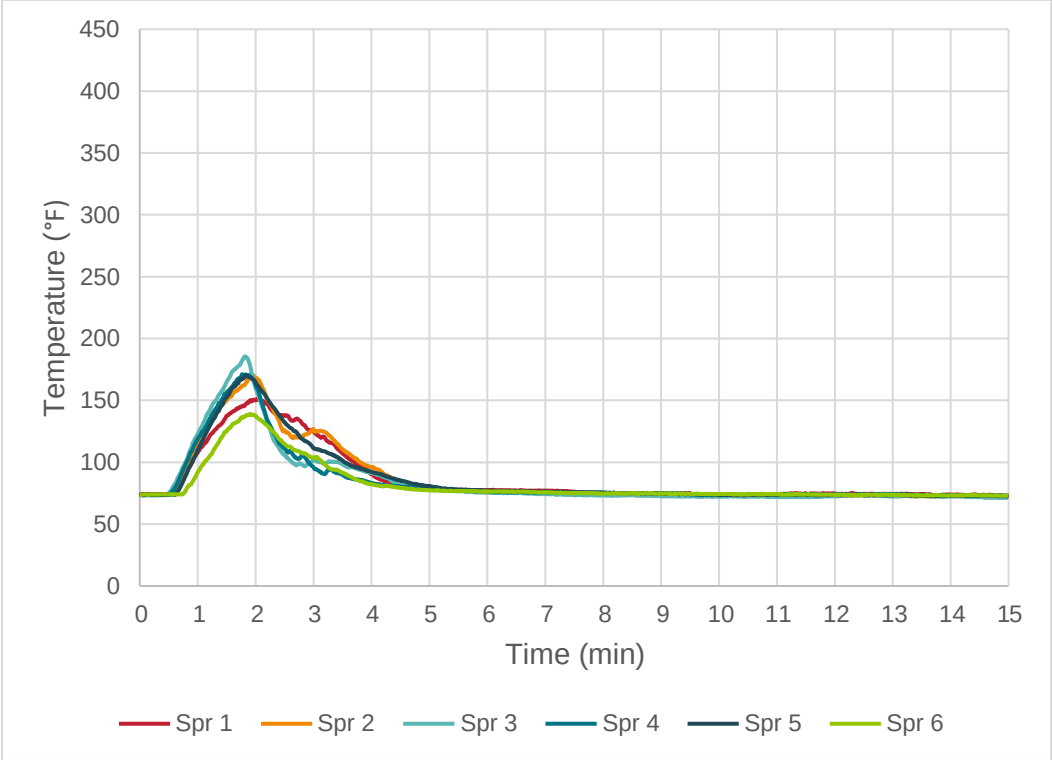


Figure 38: Test No.2 branch line 1 (Sprinklers 1-6) temperatures

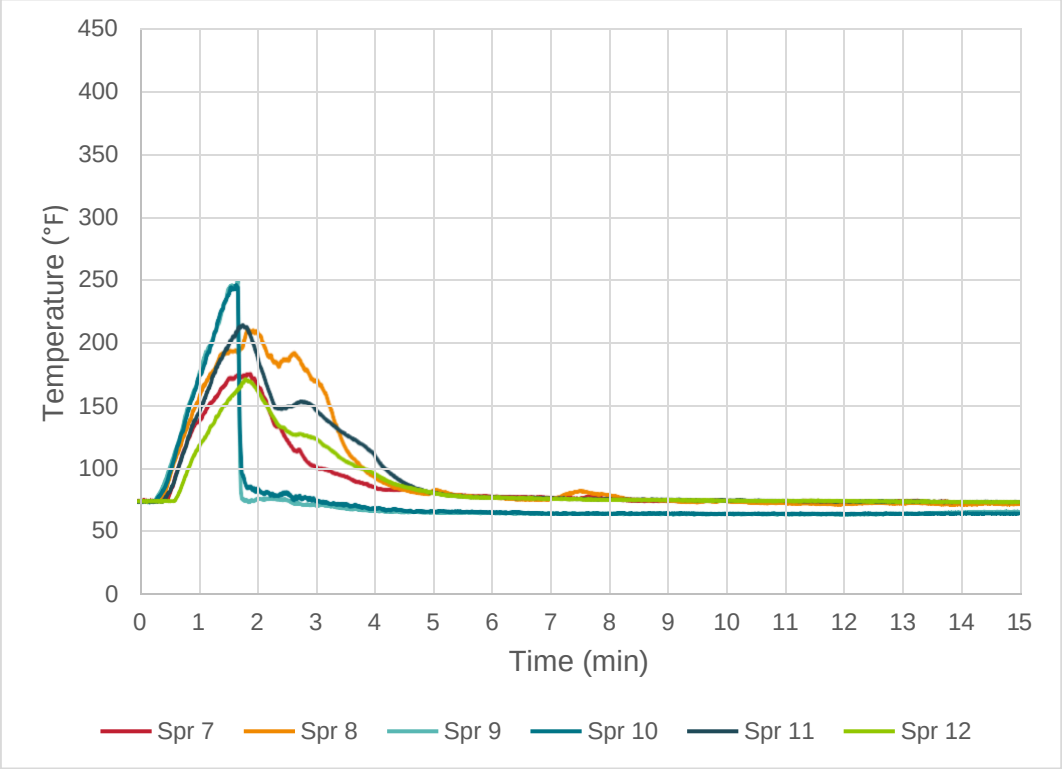


Figure 39: Test No.2 branch line 2 (Sprinklers 7-12) temperatures

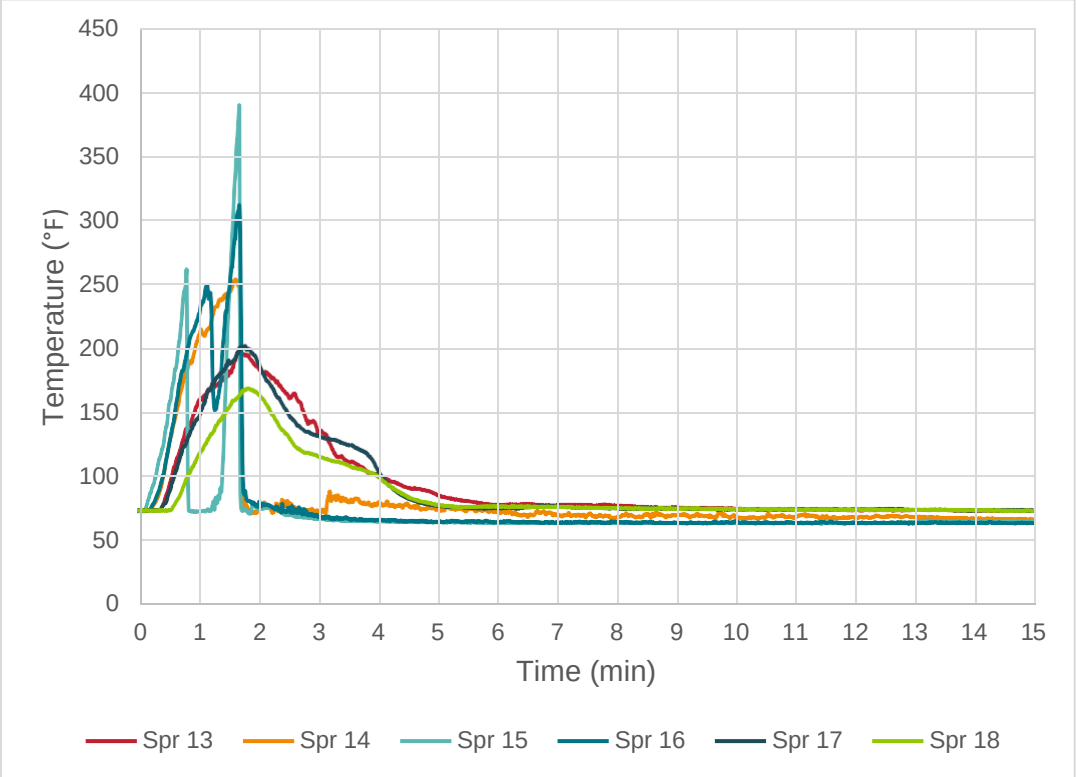


Figure 40: Test No.2 branch line 3 (Sprinklers 13-18) temperatures

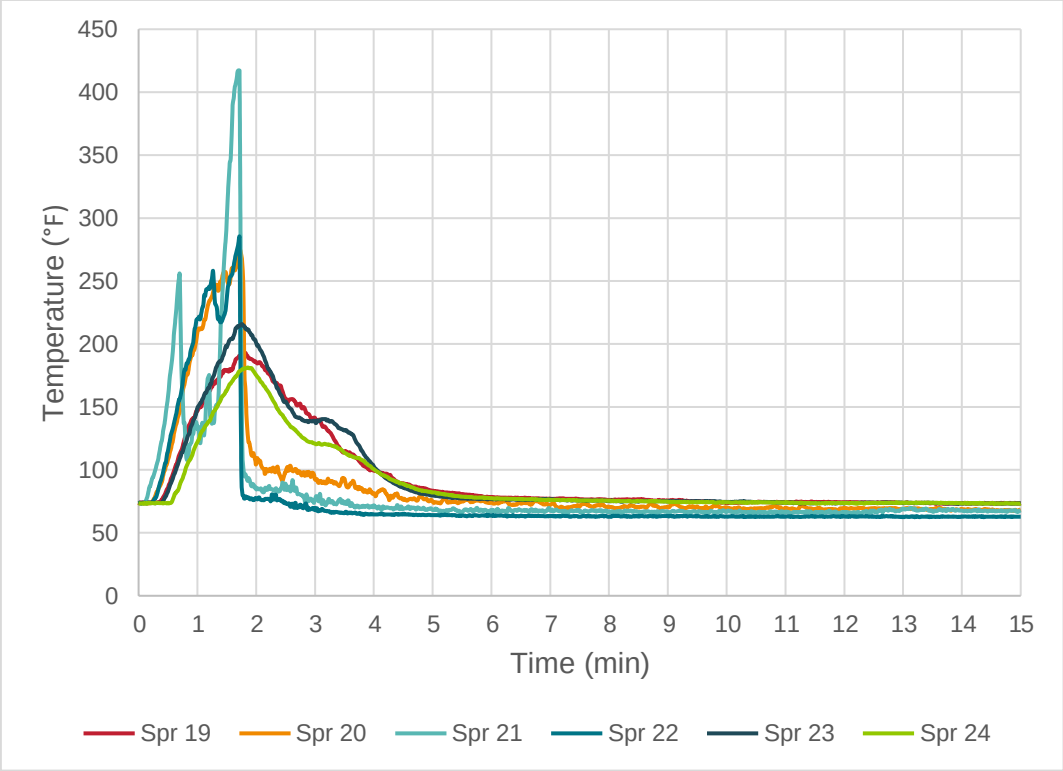


Figure 41: Test No.2 branch line 4 (Sprinklers 19-24) temperatures

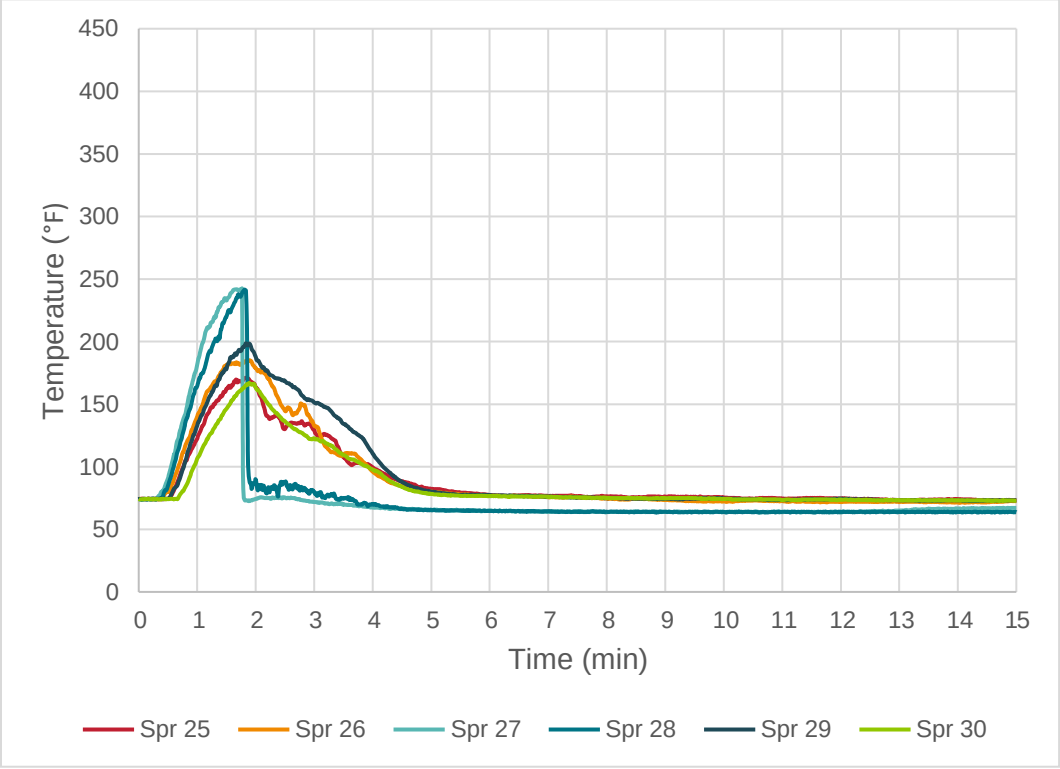


Figure 42: Test No.2 branch line 5 (Sprinklers 25-30) temperatures

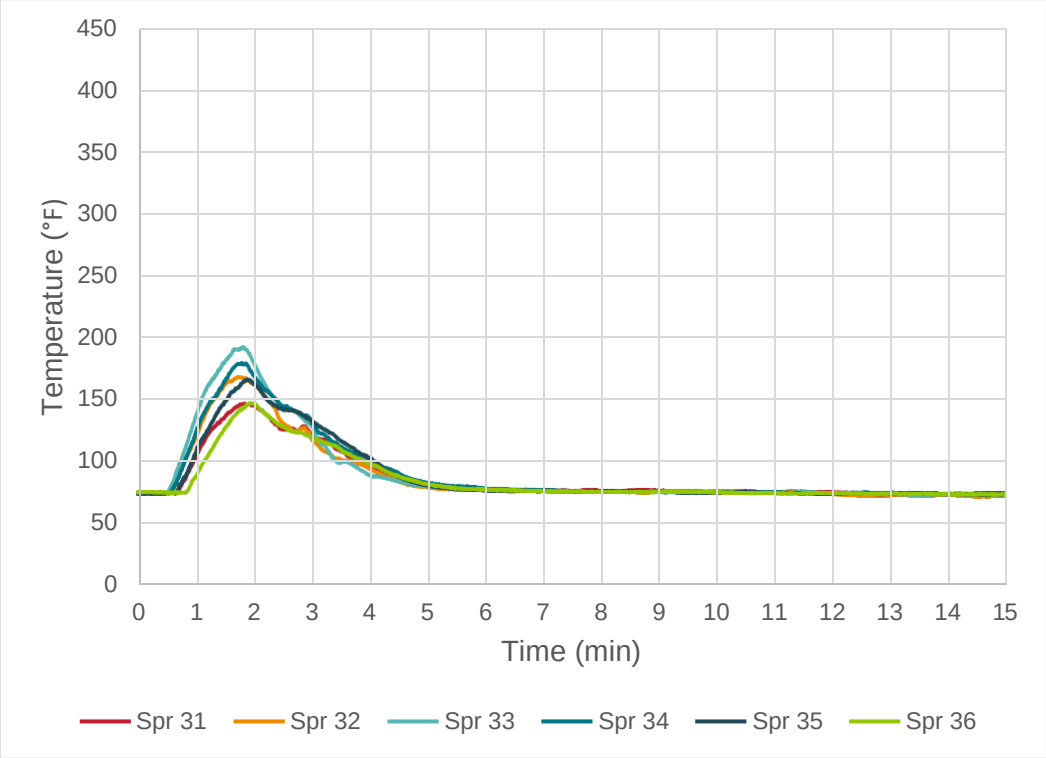


Figure 43: Test No.2 branch line 6 (Sprinklers 30-36) temperatures

Test No.3 – 50% glycerin antifreeze @ 13.9 psi

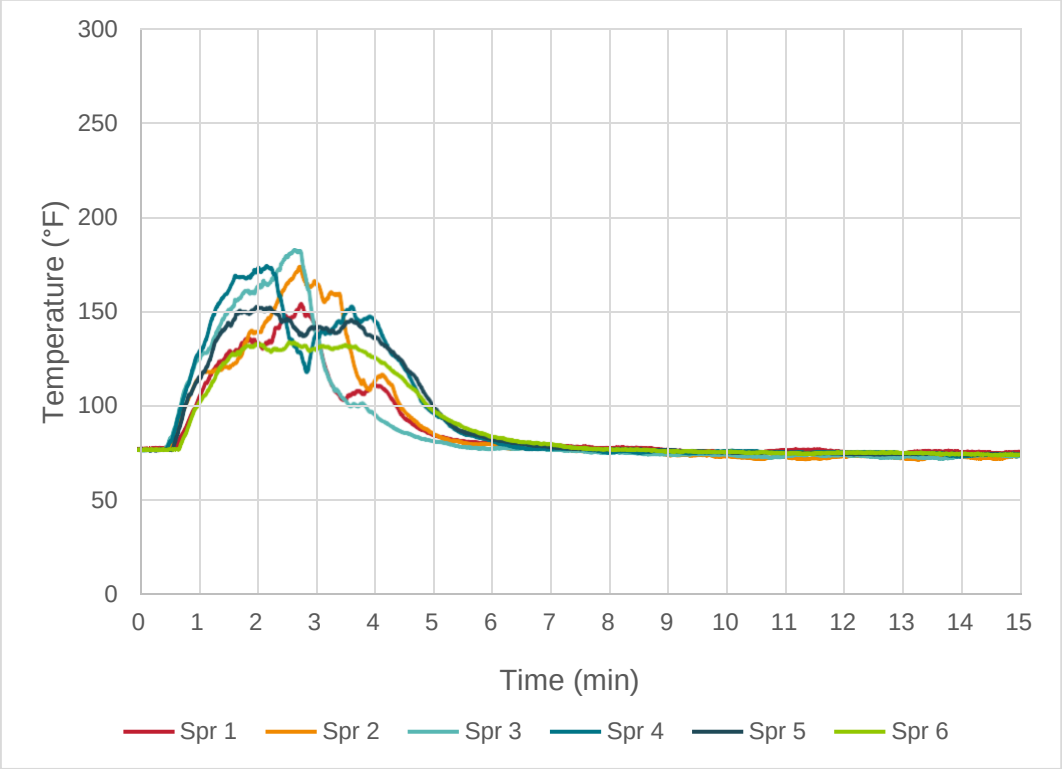


Figure 44: Test No.3 branch line 1 (Sprinklers 1-6) temperatures

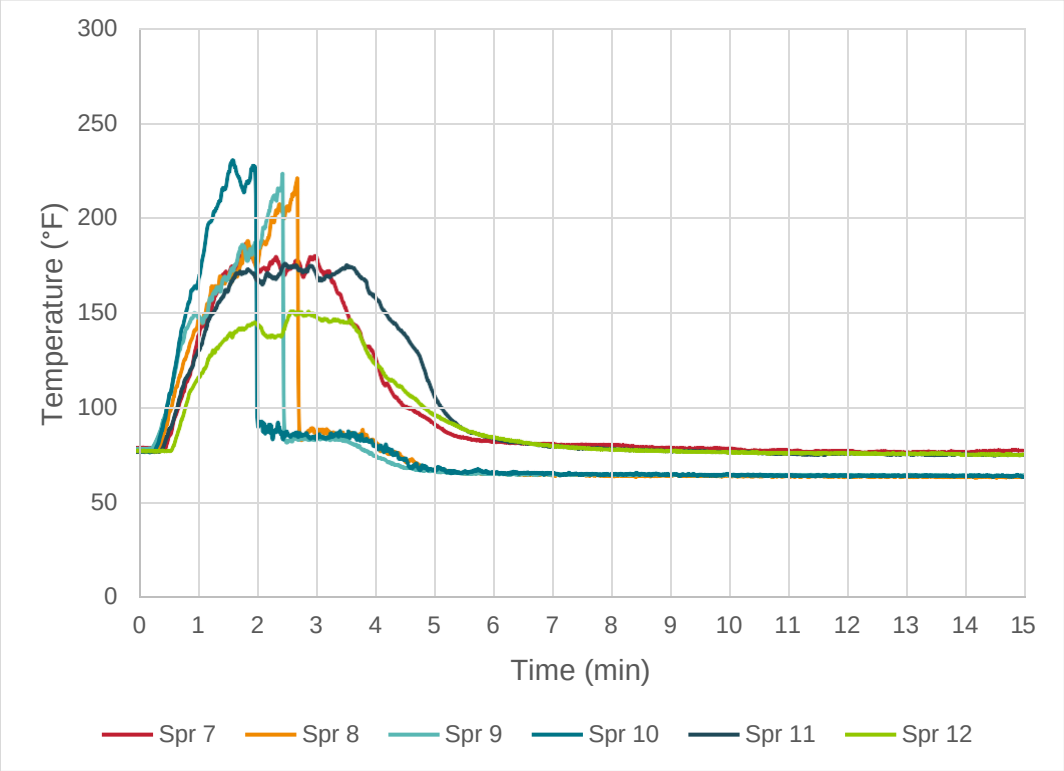


Figure 45: Test No.3 branch line 2 (Sprinklers 7-12) temperatures

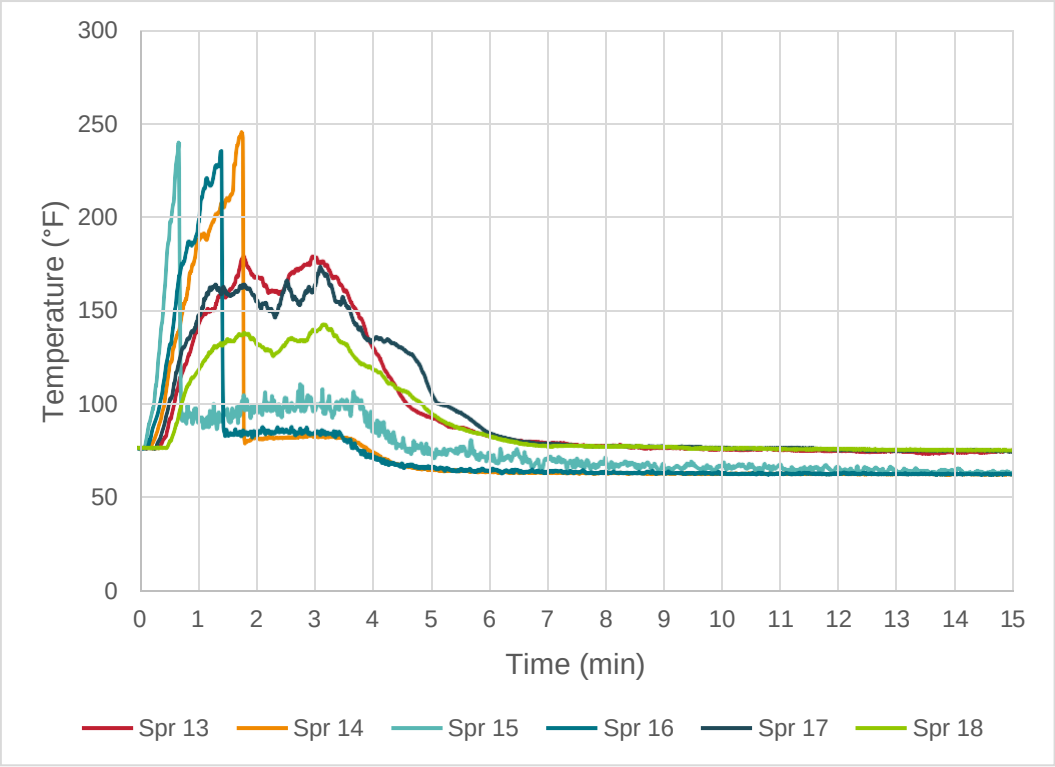


Figure 46: Test No.3 branch line 3 (Sprinklers 13-18) temperatures

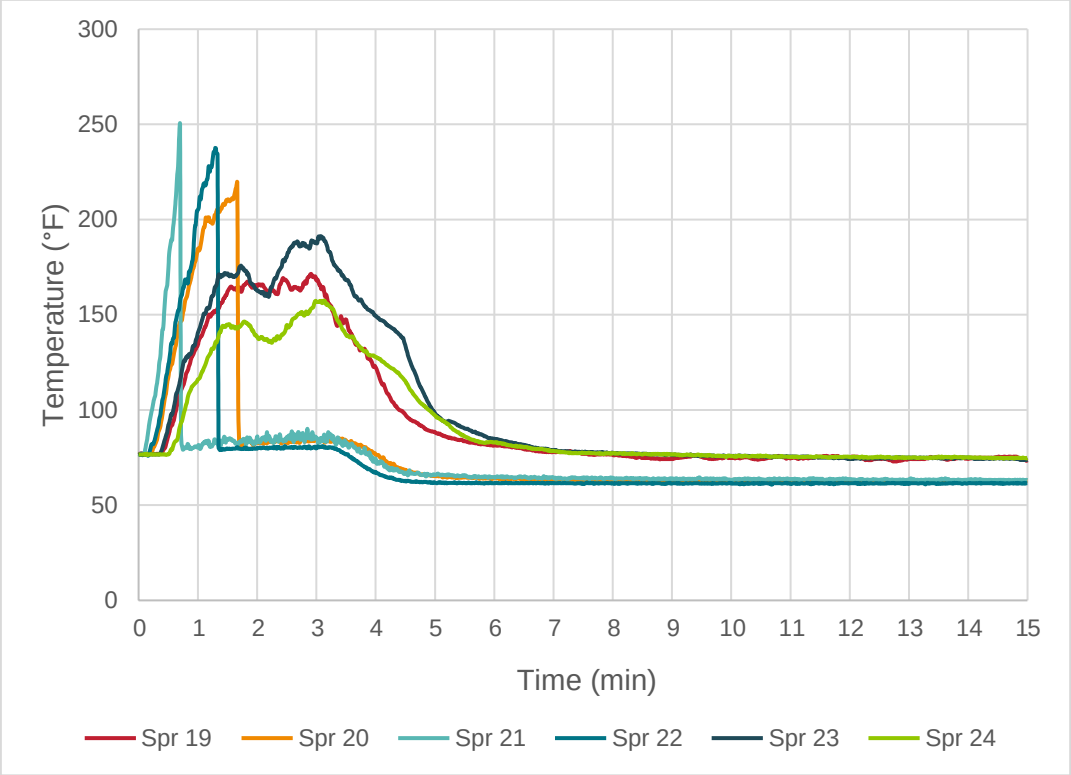


Figure 47: Test No.3 branch line 4 (Sprinklers 19-24) temperatures

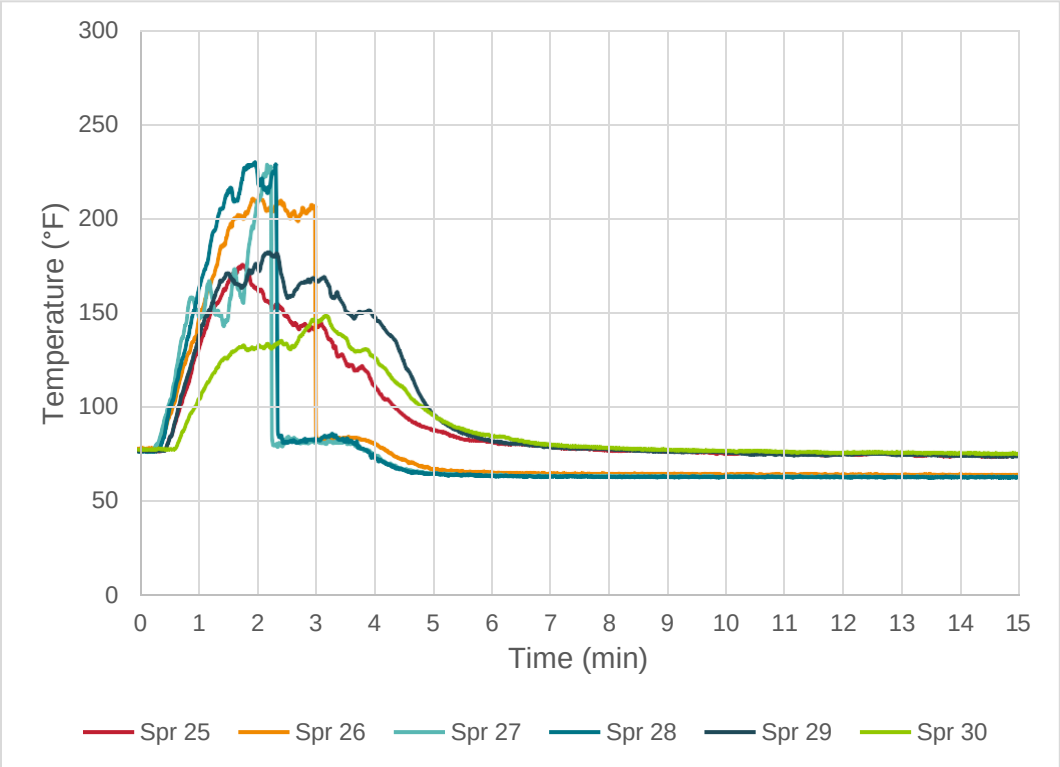


Figure 46: Test No.3 branch line 3 (Sprinklers 13-18) temperatures

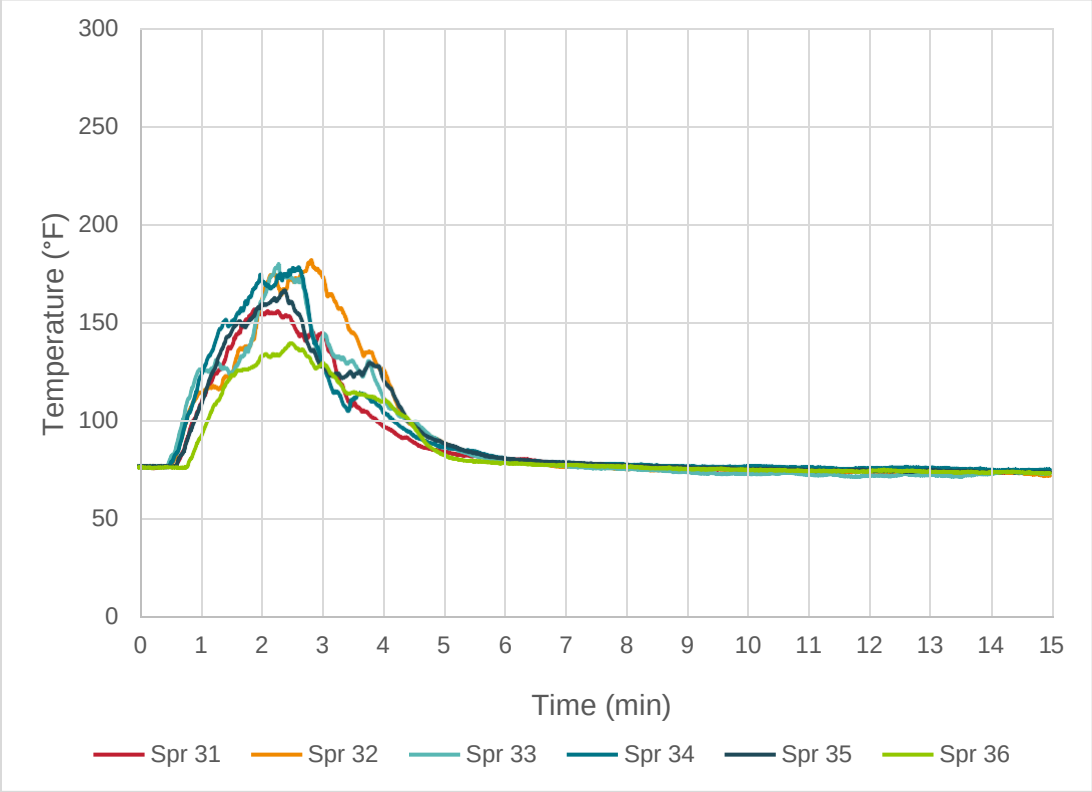


Figure 49: Test No.3 branch line 6 (Sprinklers 31-36) temperatures

Test No.4 – Water @ 24 psi

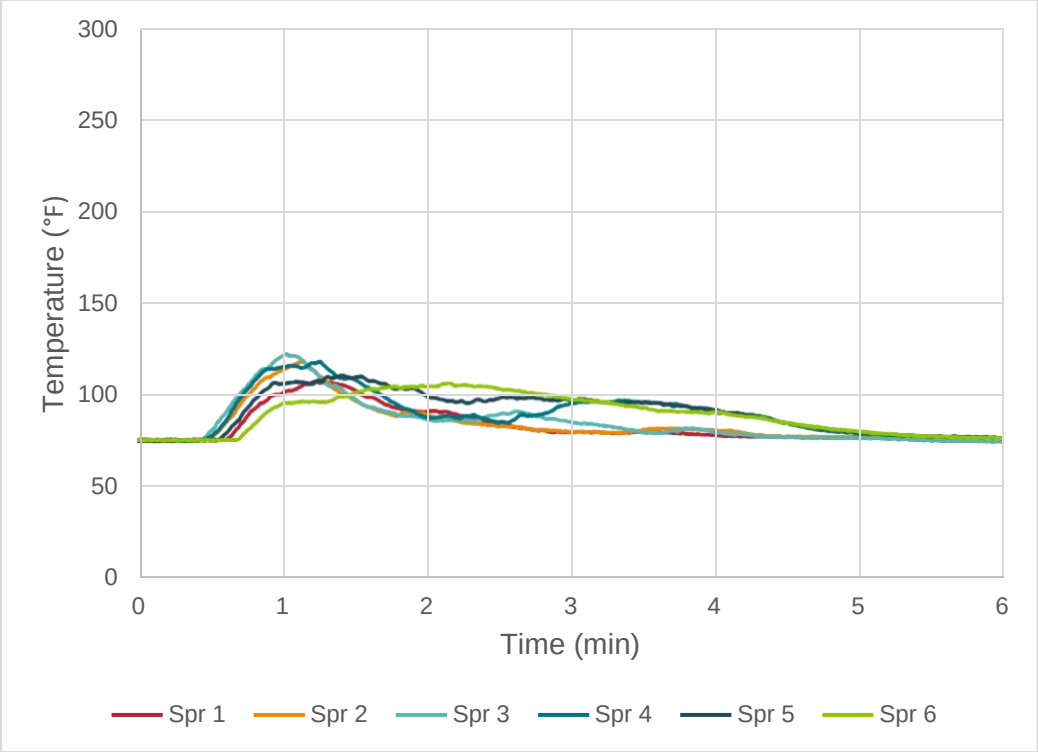


Figure 50: Test No.4 branch line 1 (Sprinklers 1-6) temperatures

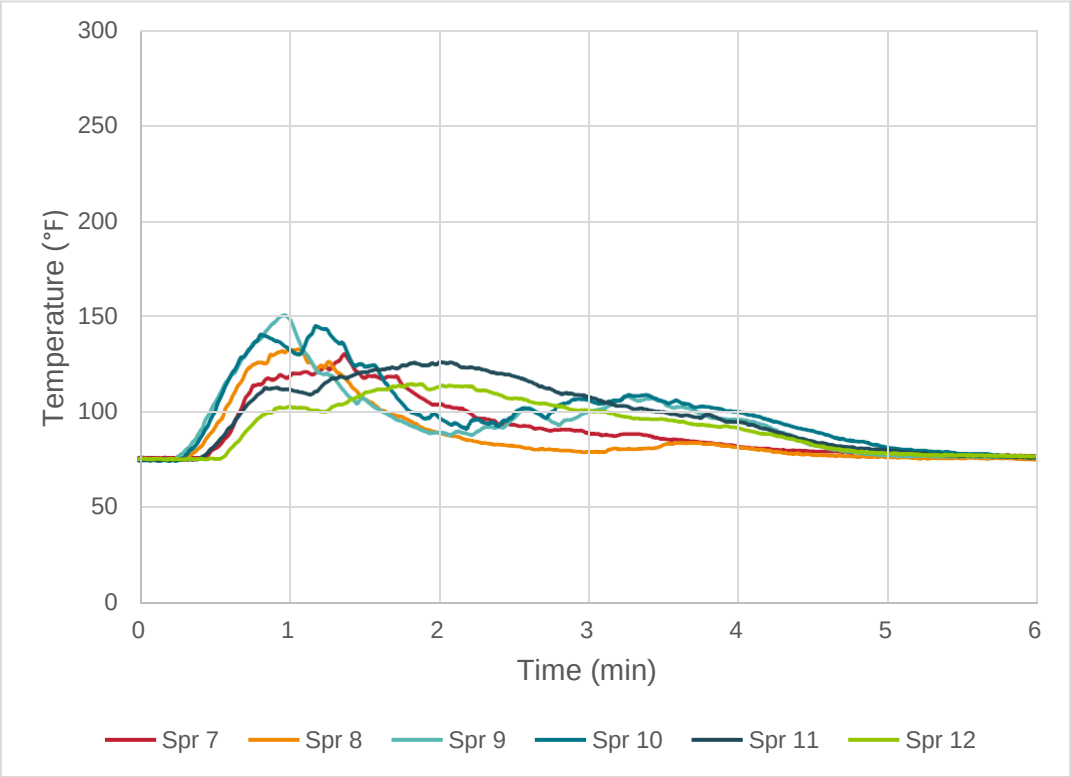


Figure 51: Test No.4 branch line 2 (Sprinklers 7-12) temperatures

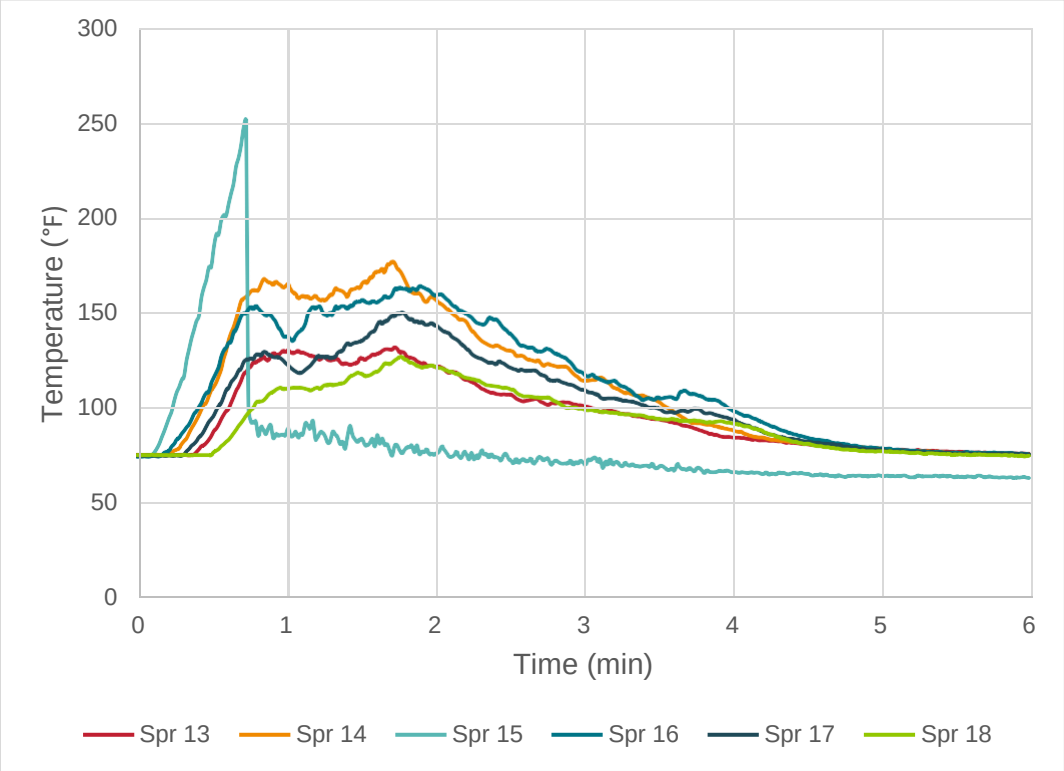


Figure 52 : Test No.4 branch line 3 (Sprinklers 13-18) temperatures

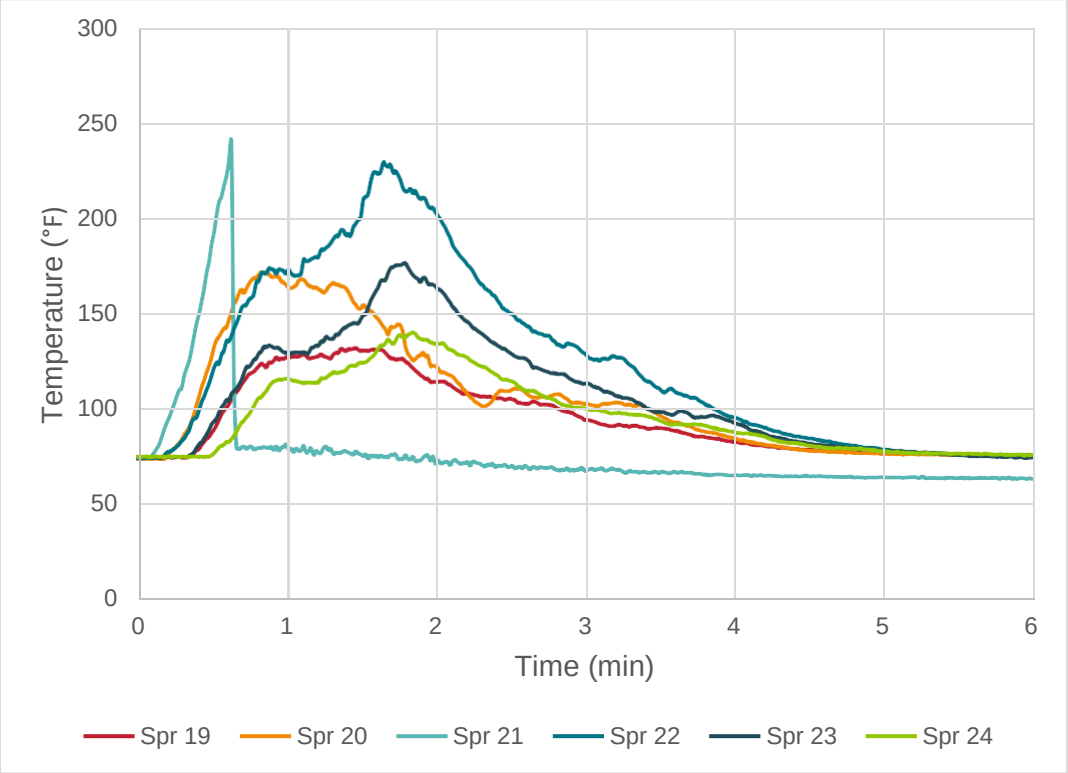


Figure 53: Test No.4 branch line 4 (Sprinklers 19-24) temperatures

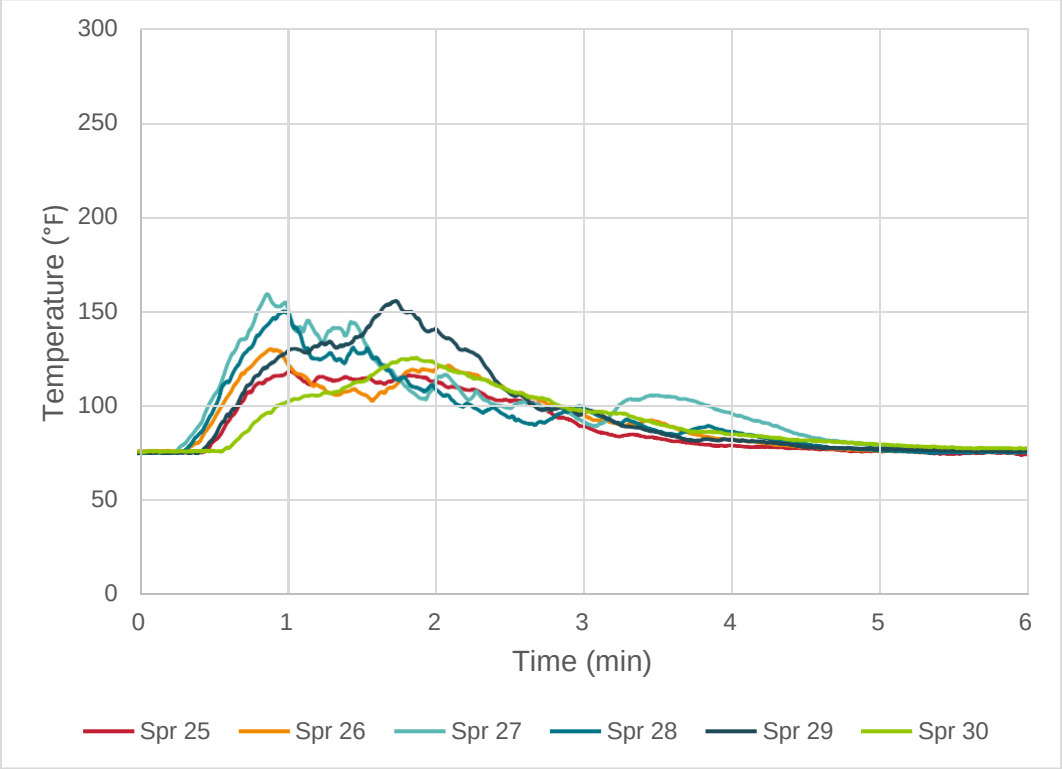


Figure 54: Test No.4 branch line 5 (Sprinklers 25-30) temperatures

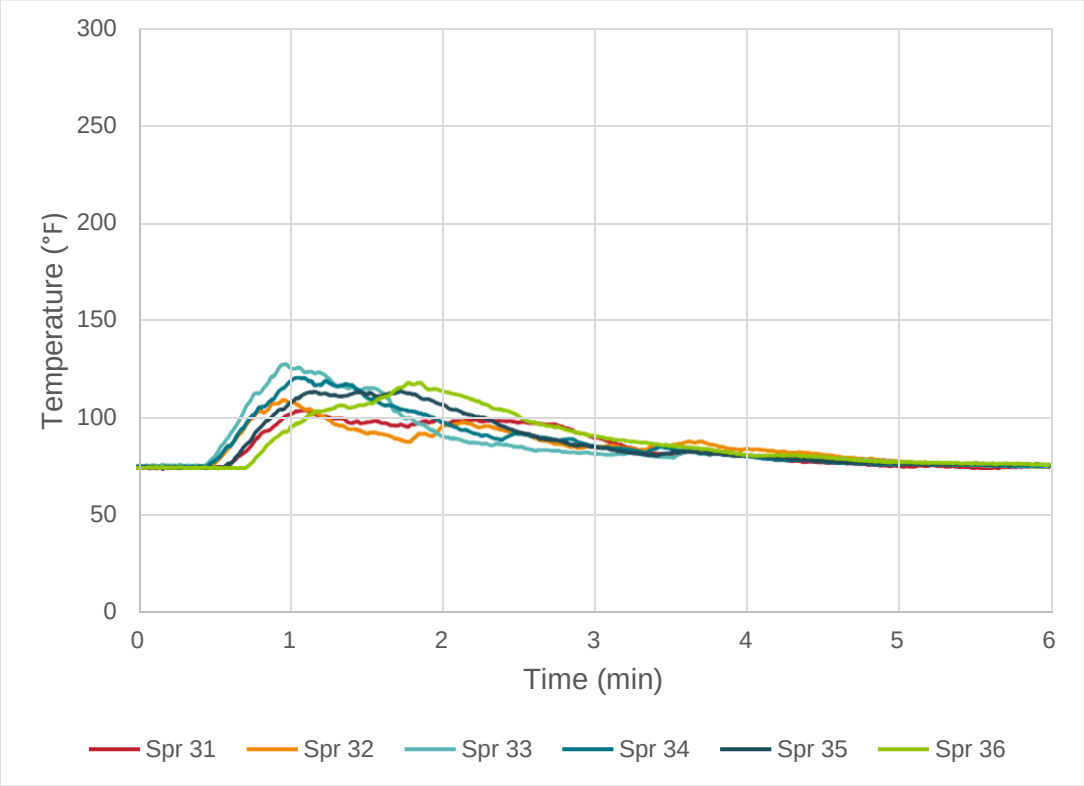


Figure 55: Test No.4 branch line 6 (Sprinklers 31-36) temperatures

Test No.5 – 50% glycerin antifreeze @ 27.2 psi

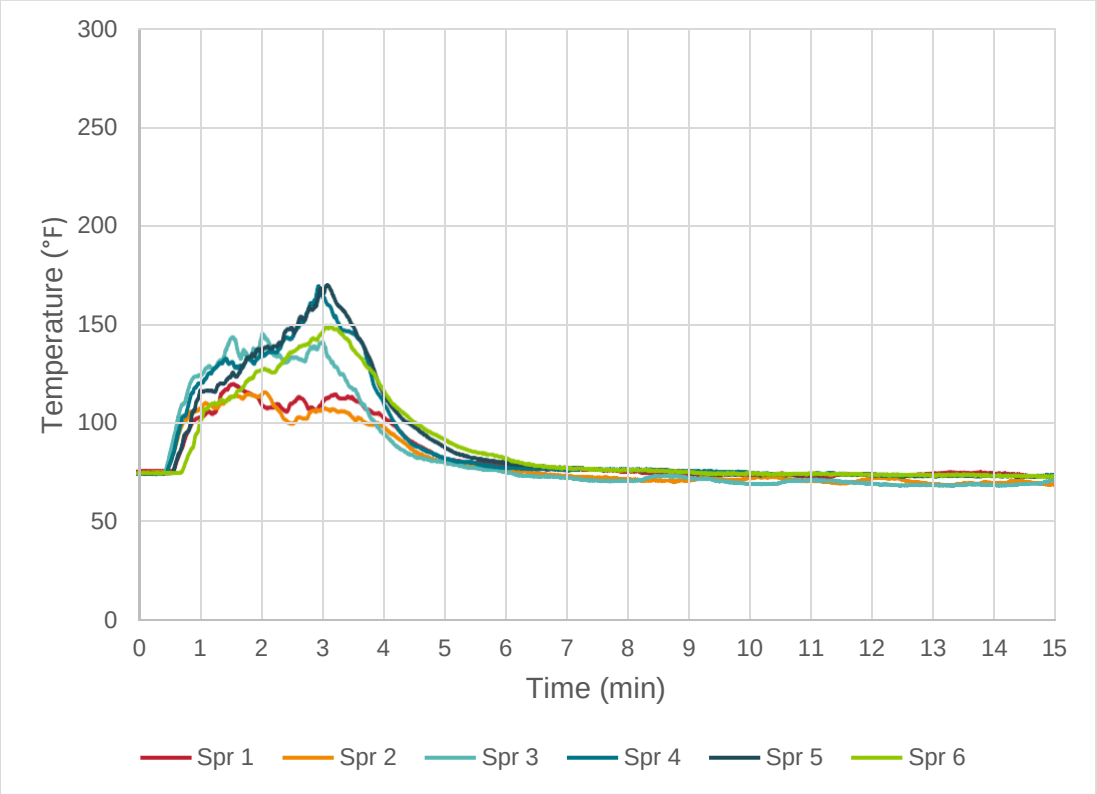


Figure 56 : Test No.5 branch line 1 (Sprinklers 1-6) temperatures

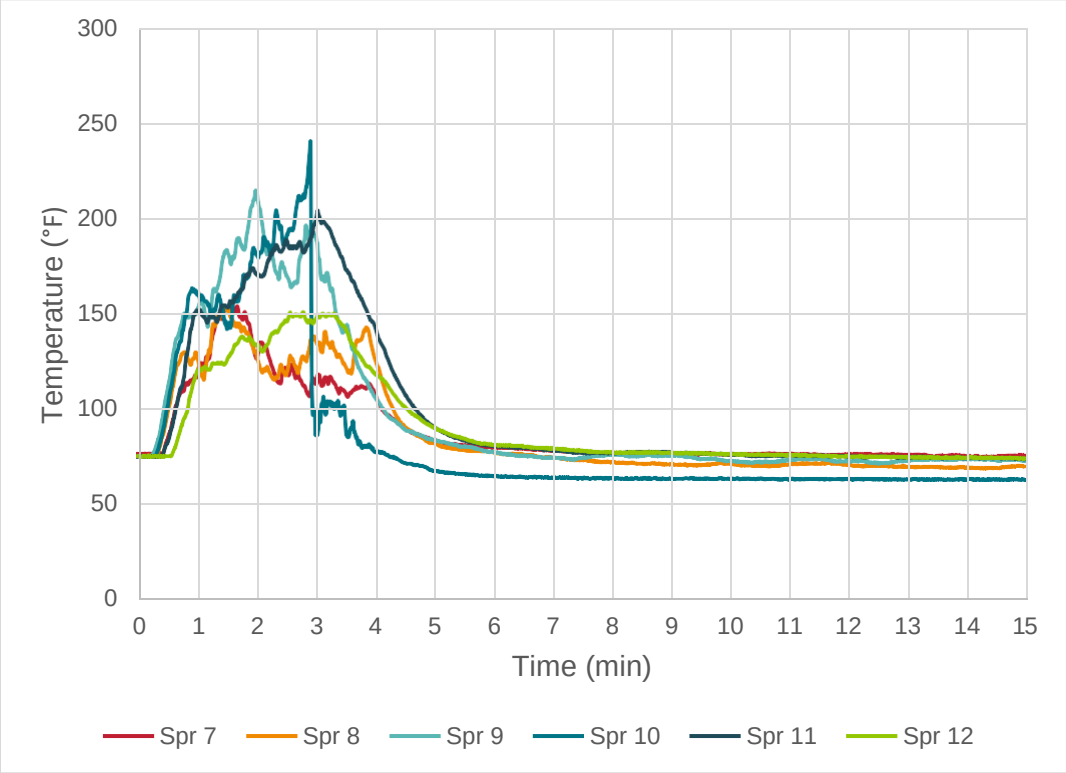


Figure 57: Test No.5 branch line 2 (Sprinklers 7-12) temperatures

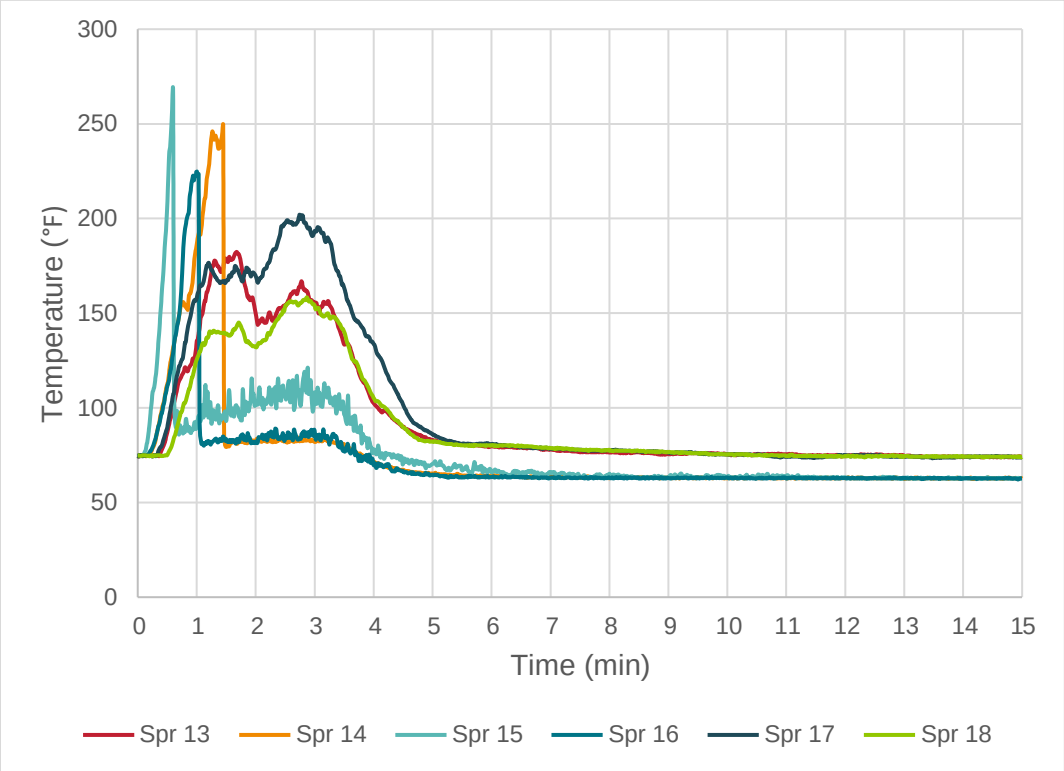


Figure 58 : Test No.5 branch line 3 (Sprinklers 13-18) temperatures

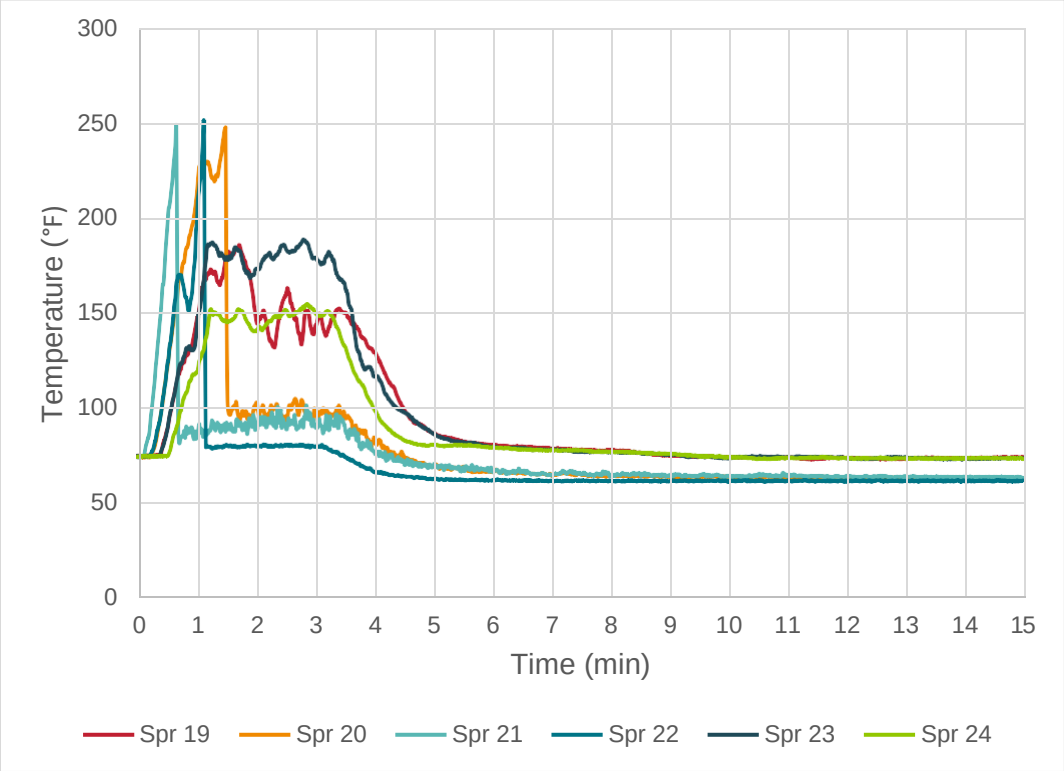


Figure 59: Test No.5 branch line 4 (Sprinklers 19-24) temperatures

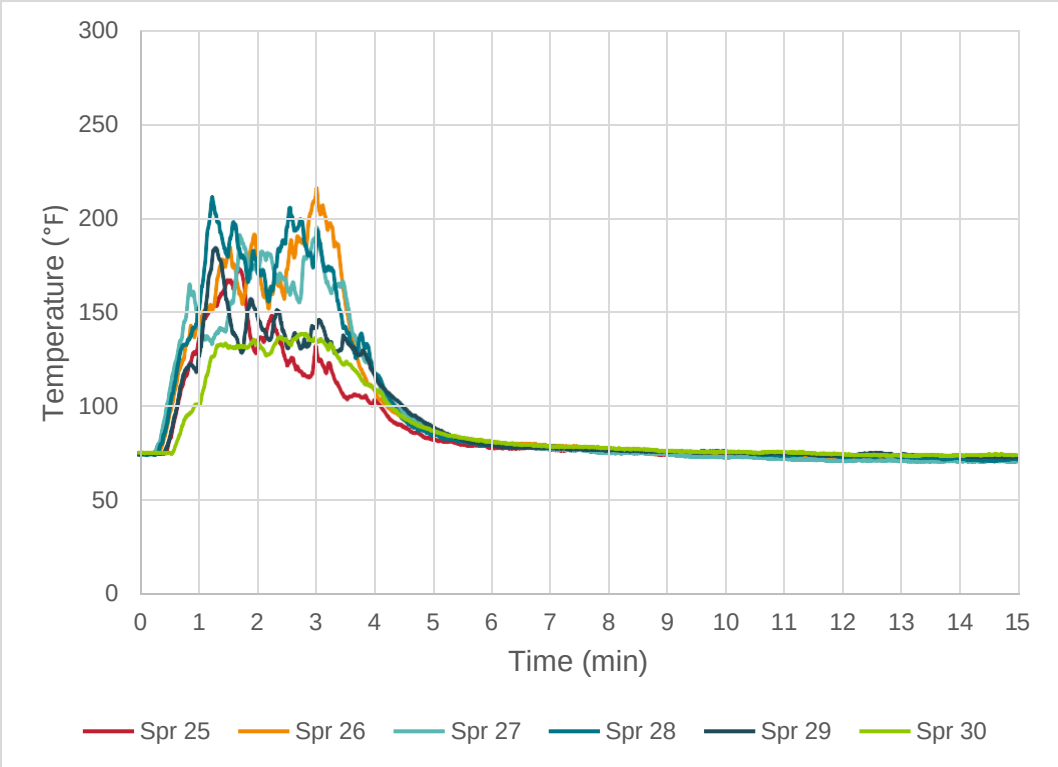


Figure 60: Test No.5 branch line 5 (Sprinklers 25-30) temperatures

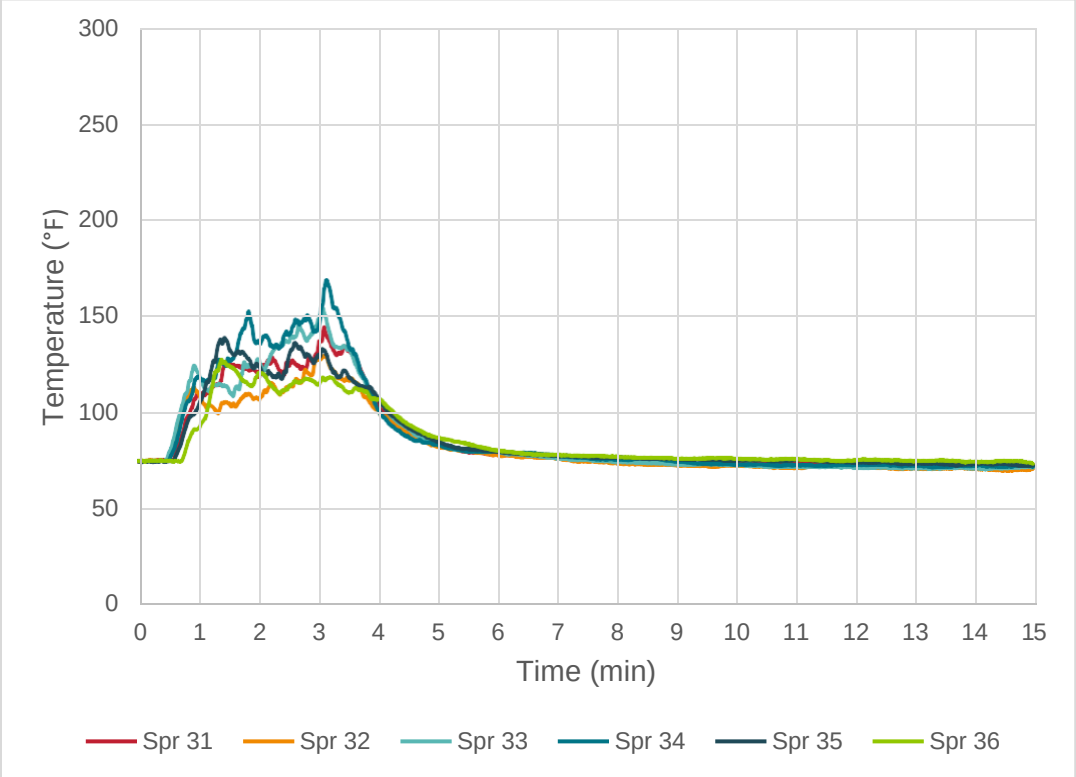


Figure 61: Test No.5 branch line 6 (Sprinklers 30-36) temperatures

Test No.6 – 38% glycerin antifreeze @ 26.4 psi

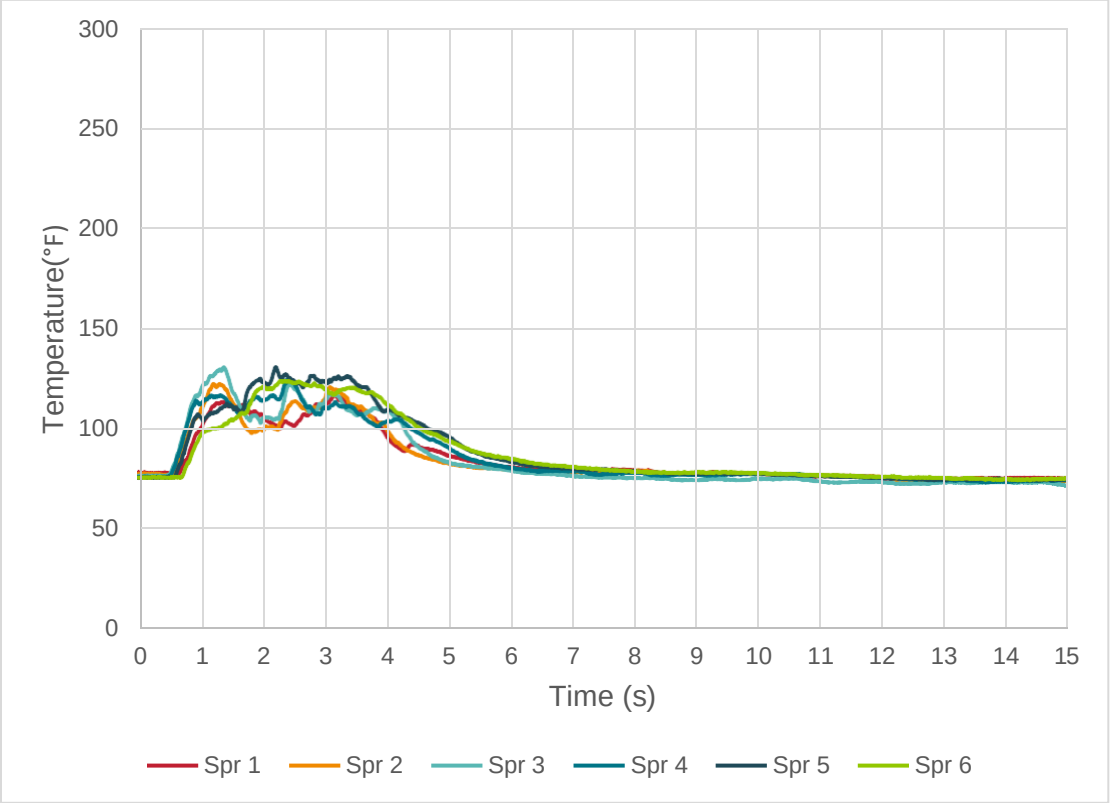


Figure 62: Test No.6 branch line 1 (Sprinklers 1-6) temperatures

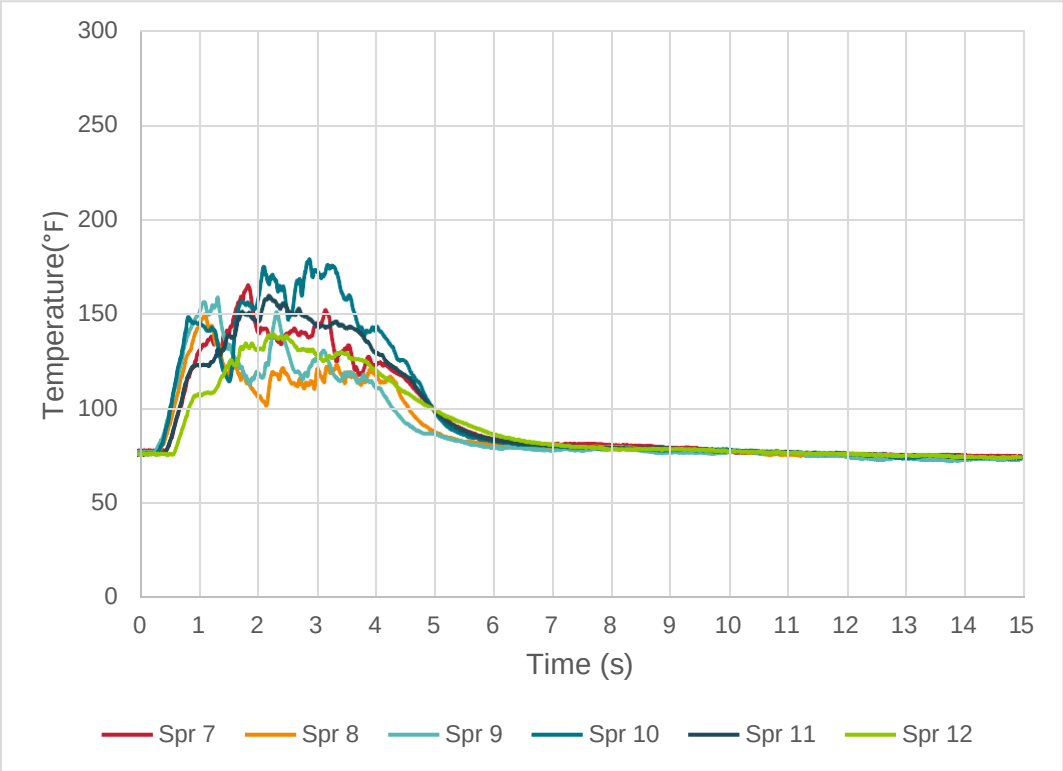


Figure 63: Test No.6 branch line 2 (Sprinklers 7-12) temperatures

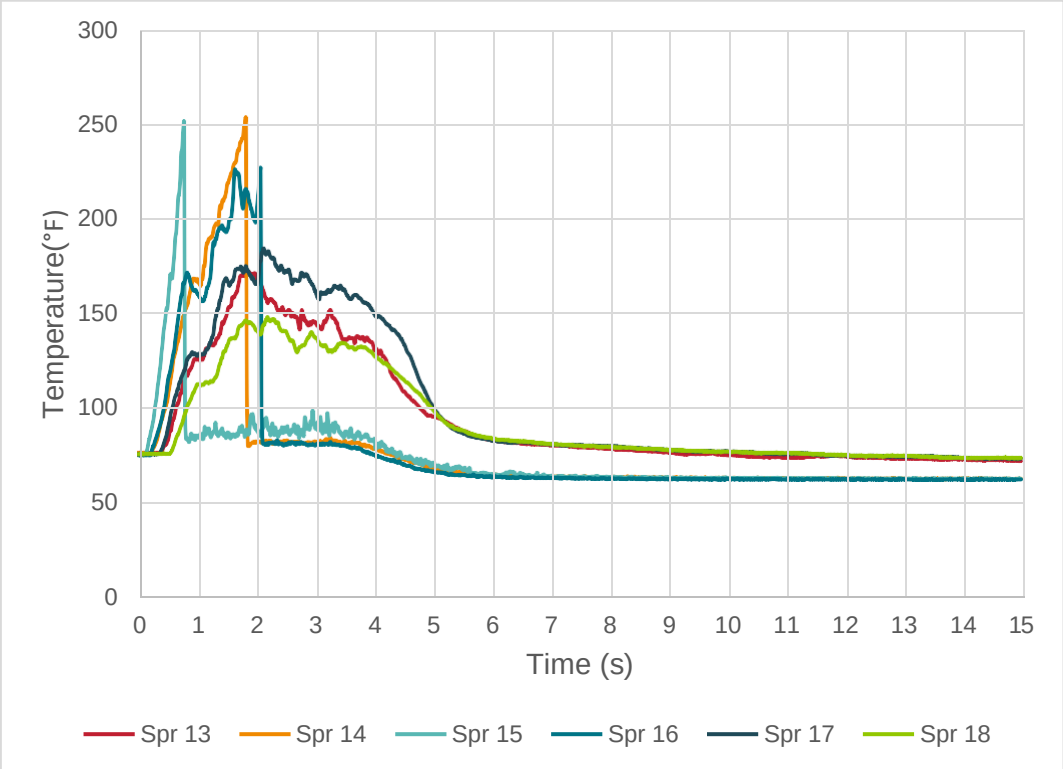


Figure 64: Test No.6 branch line 3 (Sprinklers 13-18) temperatures

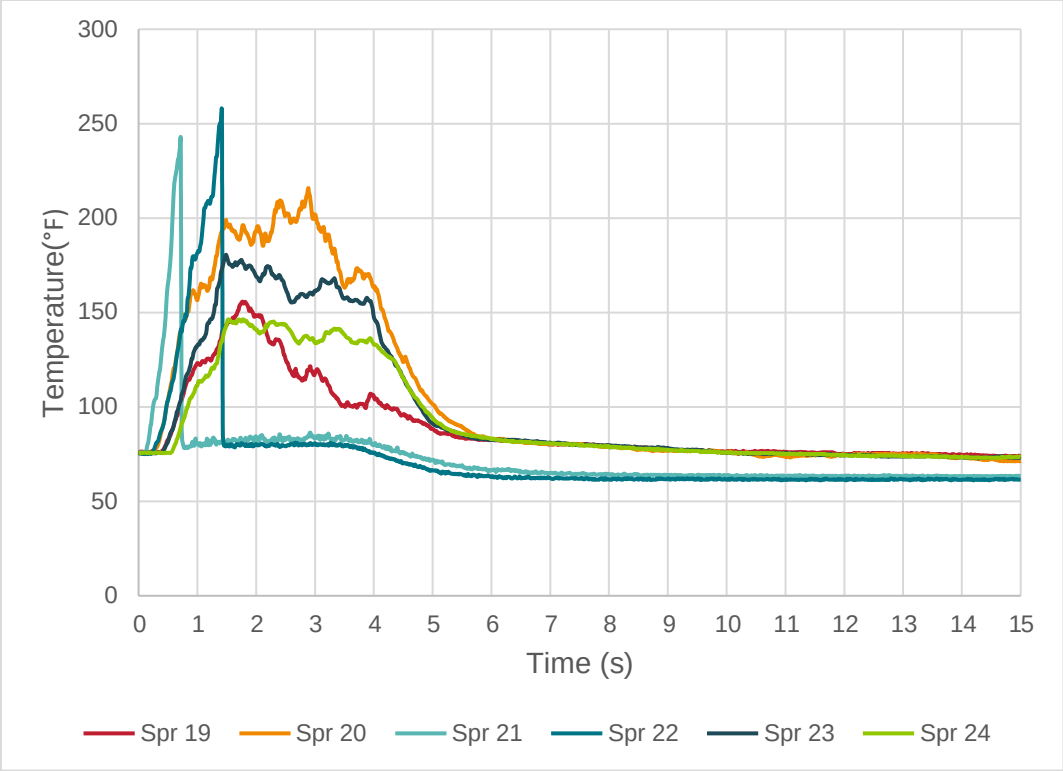


Figure 65: Test No.6 branch line 4 (Sprinklers 19-24) temperatures

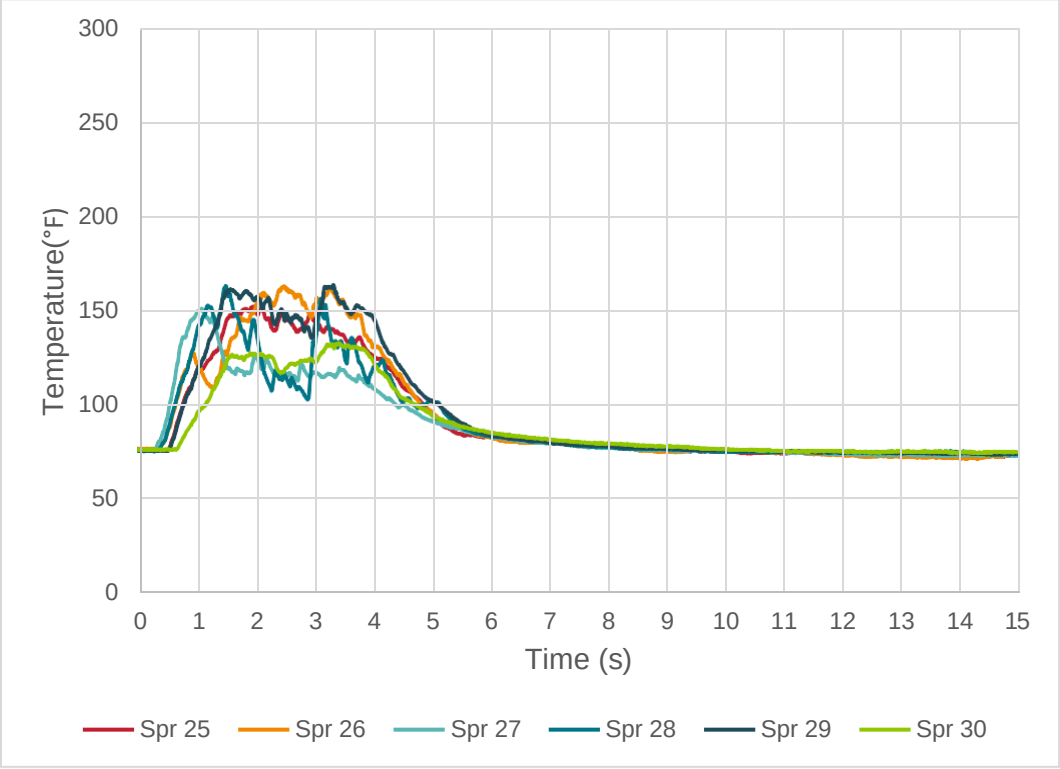


Figure 64: Test No.6 branch line 3 (Sprinklers 13-18) temperatures

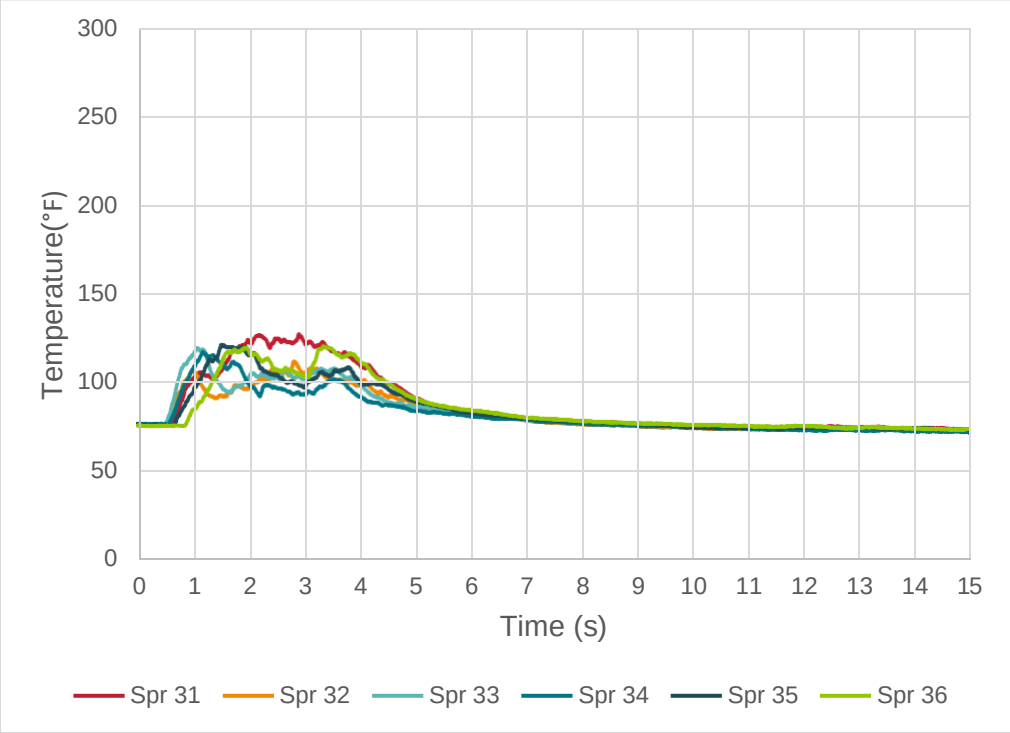


Figure 67: Test No.6 branch line 6 (Sprinklers 31-36) temperatures

Appendix C: Light hazard testing sprinkler pressure plots

This appendix provides sprinkler system pressure data. The initial noise in each pressure plot indicates activation of the first sprinklers and the subsequent compensation of the variable speed pump.

Test No.1 – Water @ 12.3 psi

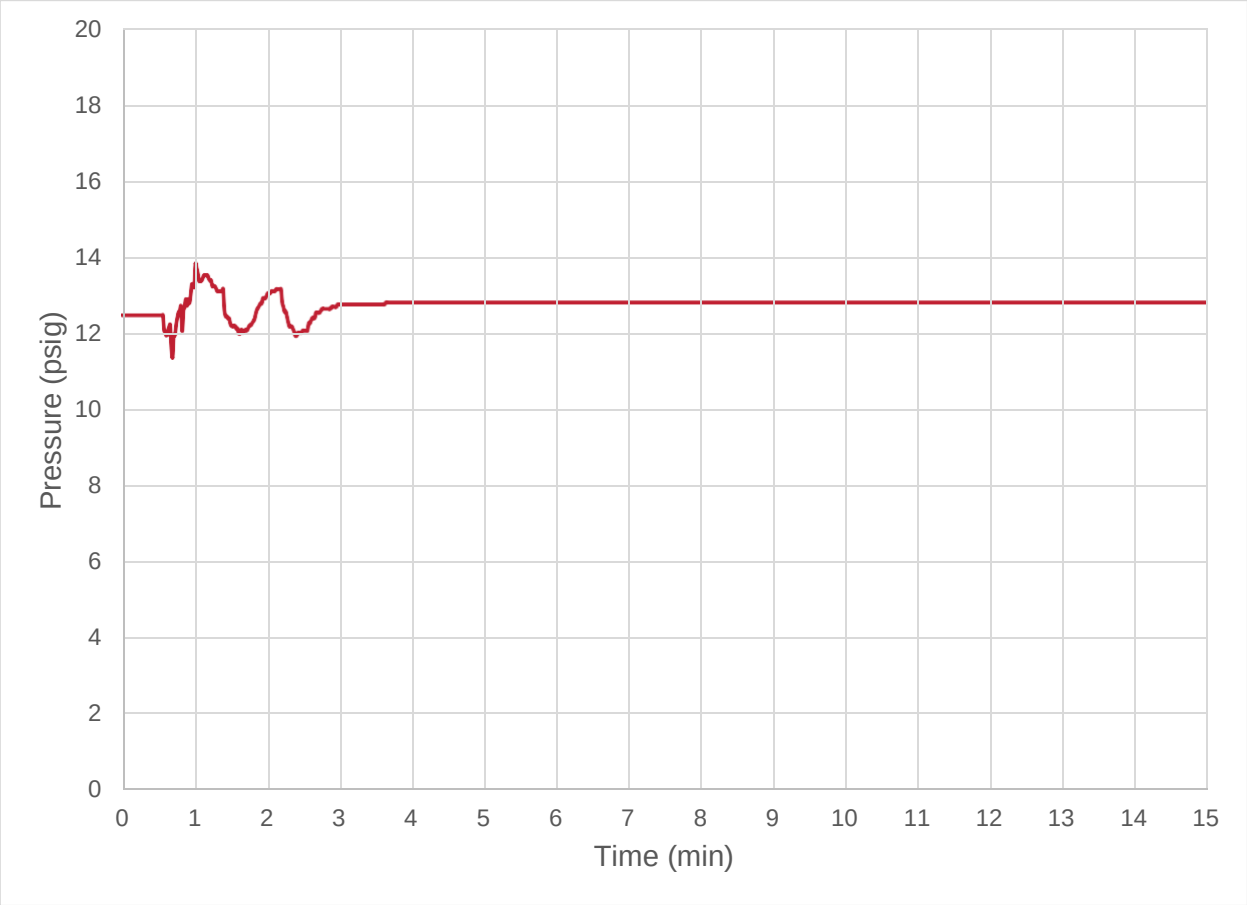


Figure 68: Test No.1 System Pressure

Test No.2 – Dry system simulation with water @ 12.3 psi

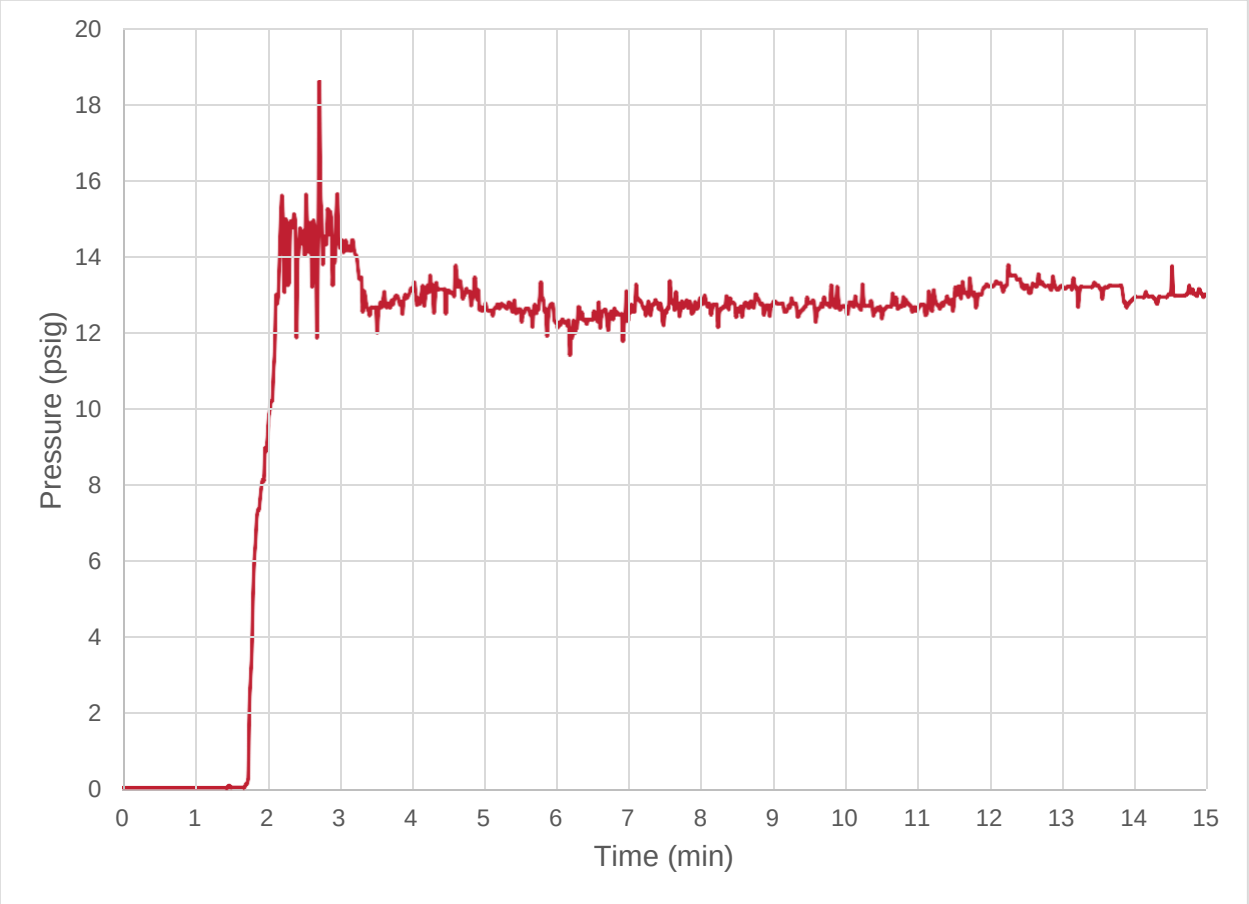


Figure 69: Test No.2 system pressure

Test No.3 – 50% glycerin antifreeze @ 13.9 psi

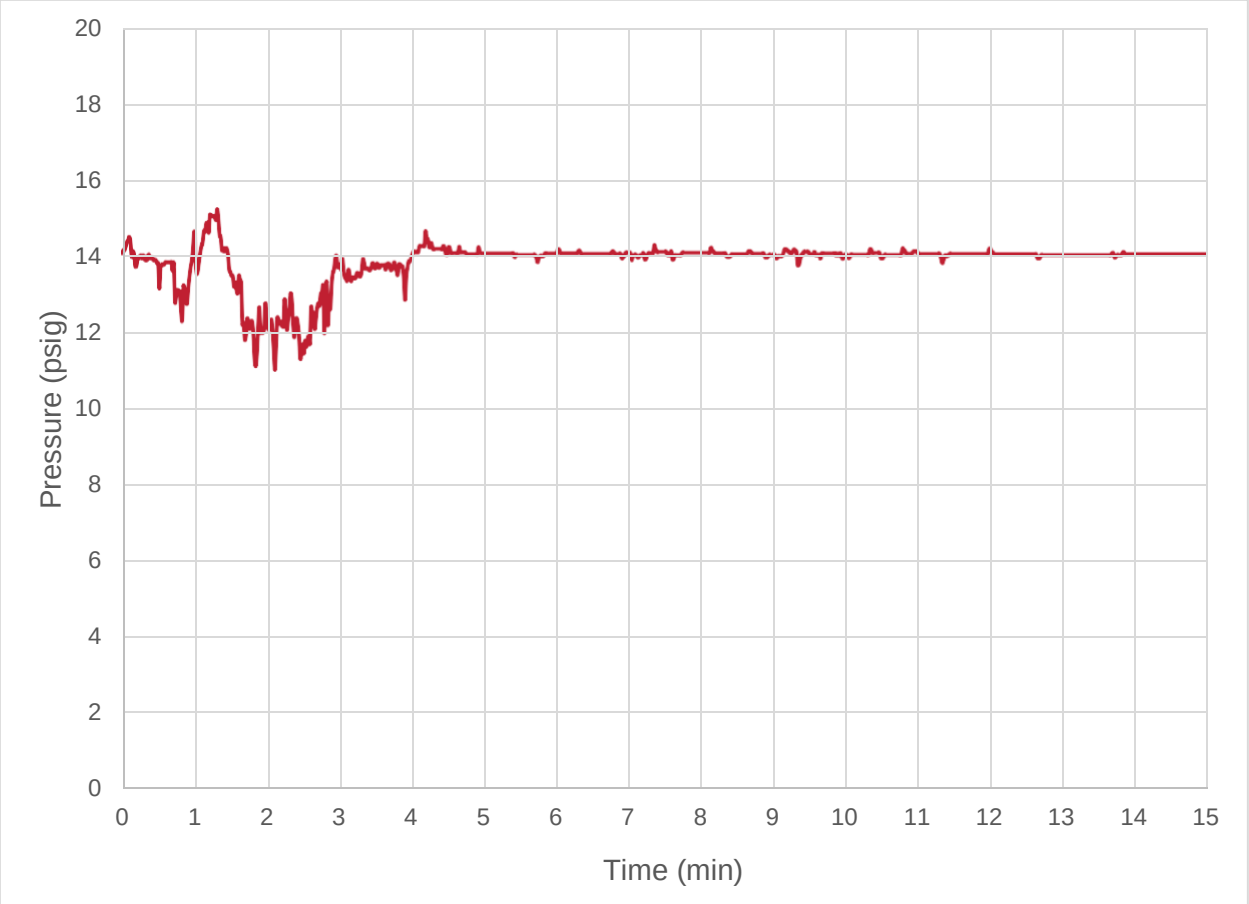


Figure 70: Test No.3 system pressure

Test No.4 – Water @ 24 psi

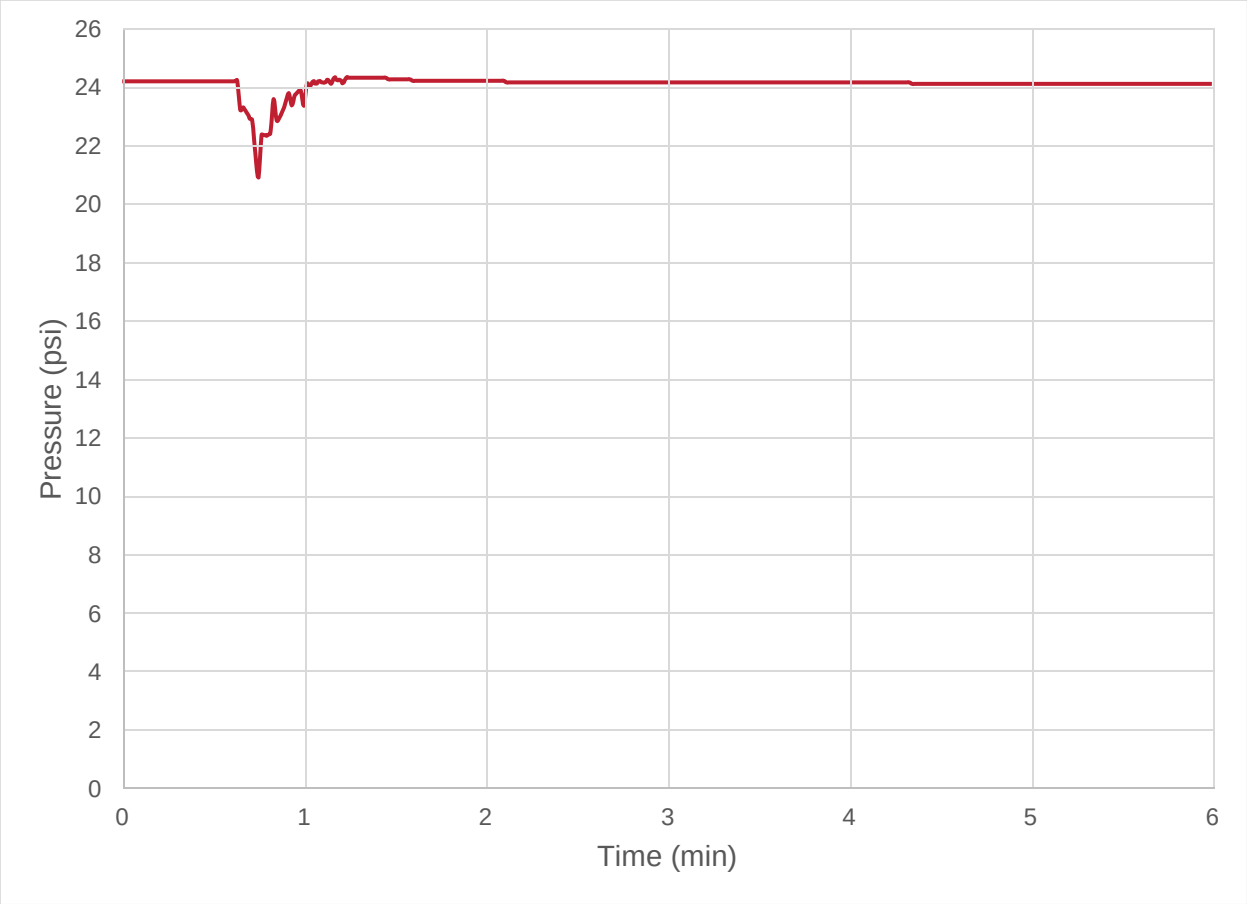


Figure 71: Test No.4 system pressure

Test No.5 – 50% glycerin antifreeze @ 27.2 psi

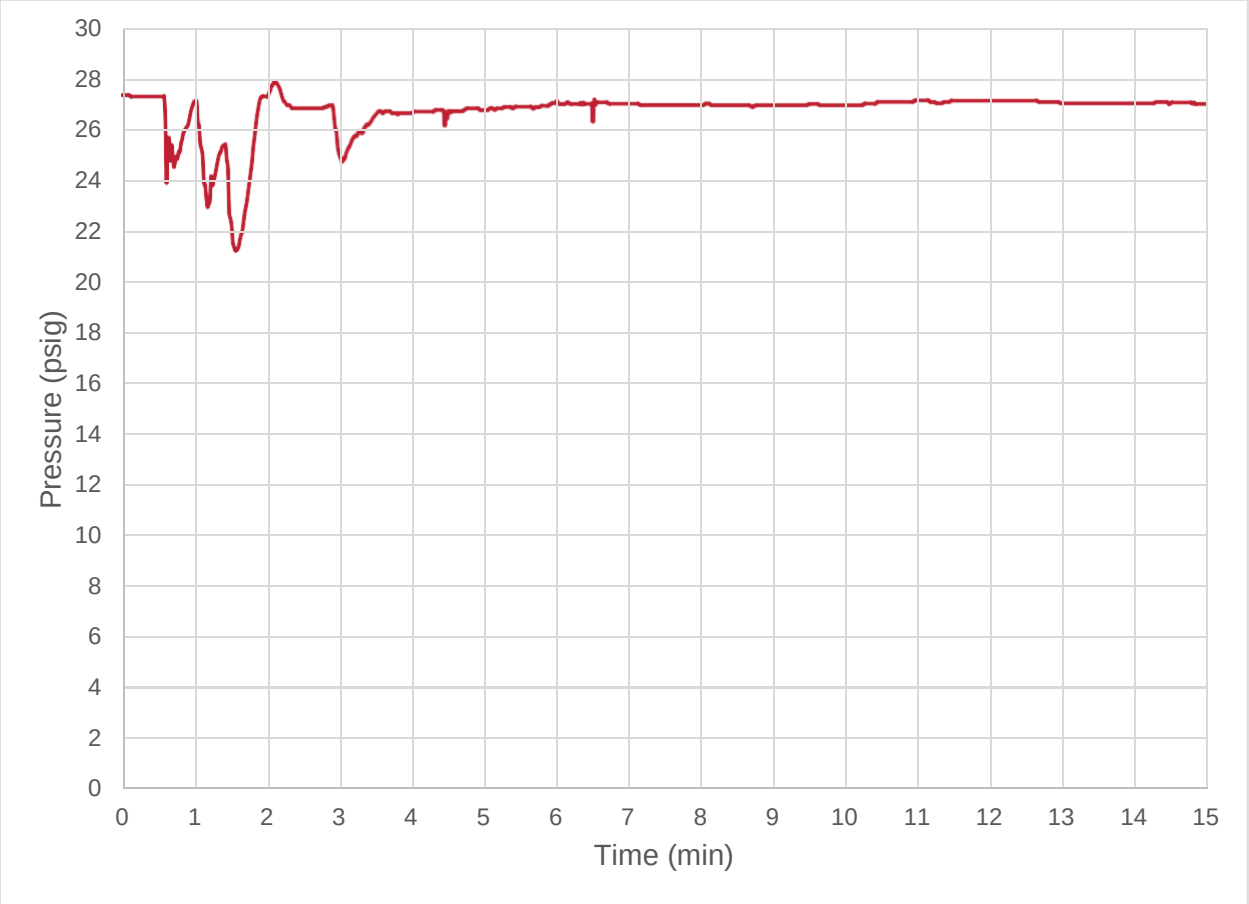


Figure 72: Test No.5 system pressure

Test No.6 – 38% glycerin antifreeze @ 26.4 psi

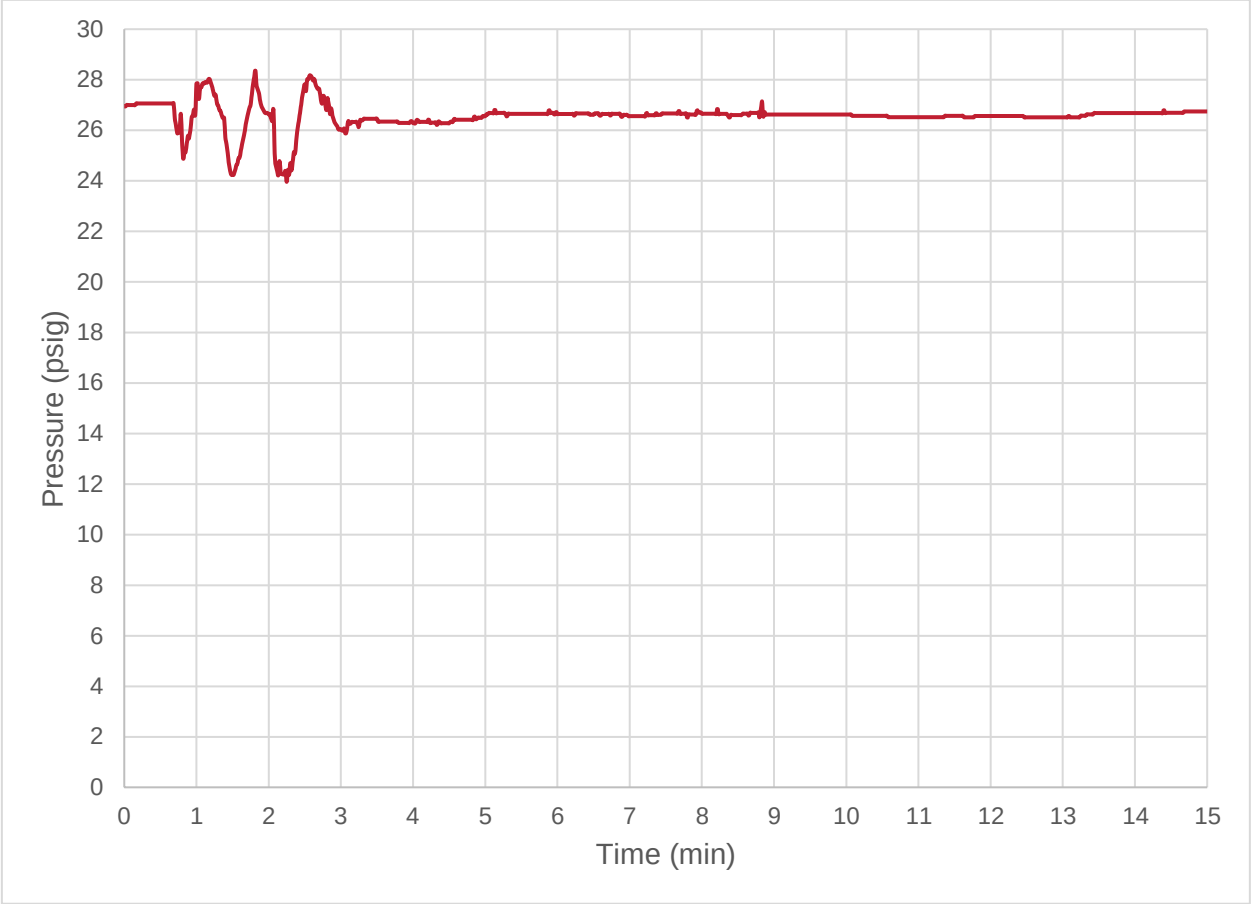


Figure 73: Test No.6 system pressure